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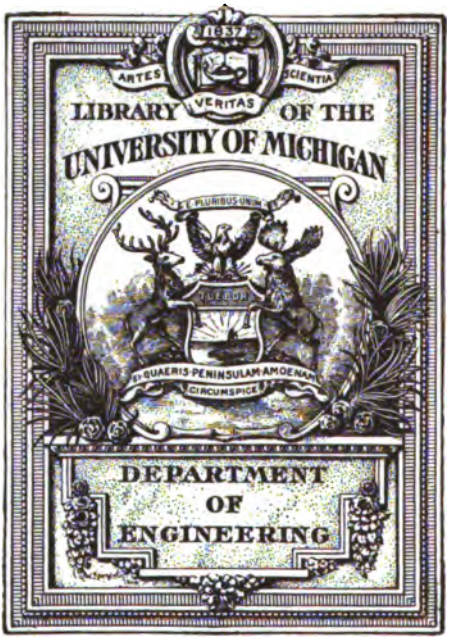


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*A paper read before the 41st meeting of the American Institute of Electrical Engineers, New York, December. 17, 1889, and discussion thereon. Vice-President T. C. Martin in the chair.*

# TRANSFORMERS.

BY HARRIS J. RYAN.

THE apparatus by means of which electrical energy of one form may be transformed to that of any other form, few engineers fail to appreciate.

So great have been the anticipated possibilities offered by the application of the modern transformer of alternate current energy that in most cases, in our country especially, has the transformer found immediate application, with but little thought or study of its exact performance. Much experimental work has been done by trial methods to the end that our manufacturers are able to supply transformers that answer for much that is desired practically, with a commercial efficiency that can be made higher than is probably possible by any other transformer of energy.

In electrical engineering, as well as other branches of engineering, for the broad application of one method or another, it is always of the highest importance that the cause and extent of every effect be thoroughly understood with regard to the mutual action and interaction of all forces and materials in relation to themselves, or to energy of one form or another.

It was with a view of obtaining, so far as possible, a clear understanding of all phenomena that take place in the commercial transformer, that the work producing the results here set forth was undertaken. It has not been possible at this time to prepare a paper as complete as has been desired, and we trust that in the near future we may add more data to that which is here presented.

In the outstart of this paper it should be said that the results of the experiments that are here presented were wrought out jointly by Mr. Ernest Merritt, of the department of physics,

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Cornell University, and the writer. What we had in mind in the work was an accurate determination of the exact performance of the commercial transformer whereby one should be able to derive results and data that should enable all phases of the performances of transformers to be understood clearly, and that should show the requisite principle of proper design. It may be well to state briefly the general method we employed. A single ten-light transformer that had been made and supplied for commercial purposes for incandescent lighting, with 1,000 volts in the primary and 50 volts in the secondary, was selected as a sample for investigation. It probably represented fairly well the average commercial performance of transformers, and might therefore be said to embody, to a certain extent at least, proportions that have proven by experience and experiment to be best for the particular purpose for which it is supplied.

This transformer was operated under the same impressed E. M. F. supplied from the electric lighting plant in which it had been used for supplying incandescent lamps commercially. It was operated with its secondary open and the same closed through one lamp, five lamps, and ten lamps, and under these several conditions the exact instantaneous values of the ever varying primary impressed E. M. F., primary current, and the E. M. F. at the terminals of the secondary were observed. Again under these several conditions the square roots of the mean squares of the above values and of the secondary current were also observed. Then with these observations, the dimensions and the details of the construction of the transformer, many of the facts and performances that the engineer is concerned with, are brought to light.

Naturally the first thing to be considered is the electrical measurements and how they were made. A point on the armature of an alternator always passes a fixed point in its circumference at a time corresponding to a definite value of the varying E. M. F. and current, alike, with regard to these quantities in the primary feeders, transformer, primary or secondary, etc., so long as the conditions remain constant. In our experiments we were only concerned with the values of the E. M. F. impressed at the terminals of the primary, the primary current and the secondary E. M. F., then by changing the position of the fixed point relative to the machine, the rotating point of reference in the armature

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would pass the new position of the fixed point at corresponding different values for the primary E. M. F., primary current, and secondary E. M. F., with respect to themselves and the position of the armature.

In Fig. 1, B, L, is a prism of hard rubber, bearing a projecting strip of brass, B, that on its upper side is filed to a dull edge. This edge is taken as a fixed point on the armature. An arm, F D, is arranged to rotate about D as a centre, a point that is in line with the axis of rotation of the armature. A semi-circular board of hard wood, attached rigidly to the dynamo frame, serves both

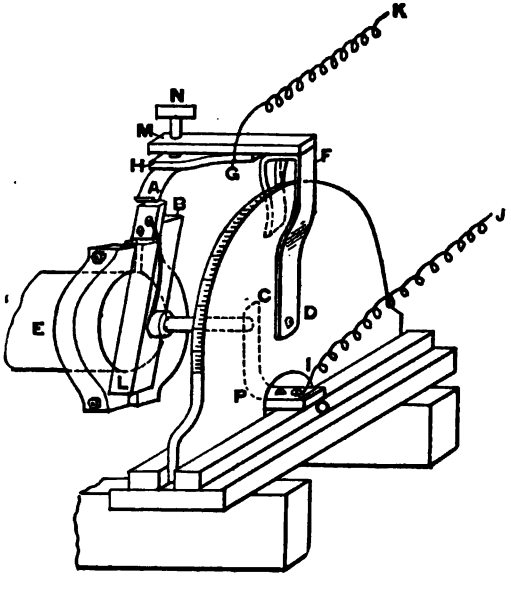


FIG. 1.

as a support for this arm and a circumferential scale whereby the position of the arm may be observed relatively to the machine. The arm is made of brass and given the form shown in the figure. It was bent into a U shape at the top so as to pinch the board and thus remain fixed in any position desired. At the top of this arm is mounted a bar of hard rubber projecting toward the dynamo parallel to the armature axis. On its under side, fastened at G, is a brass strip, a tongue, H, A, of spring brass is attached at the end and at right angles to the brass strip H G, as shown. The position of this part of the apparatus is carefully adjusted so

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that the point about which the arm rotates is in line with the axis of rotation of the armature and the sharply upward curved end of the tongue H A, just over the edge of the brass strip at B. Then when the armature is rotated the strip H G may be sprung inward radially by turning the thumb-screw N, until the tip of the tongue A is heard to just lightly touch the edge at B as it passes. The arm may then be adjusted by hand so that the tongue will touch the fixed edge on the armature at any desired phase of the primary E. M. F., primary current or secondary E. M. F. and current. Coaxially with the armature a small brass rod is mounted on the bar of hard rubber B L. It is connected metallically to B by means of a wire. At O, on the frame work supporting the

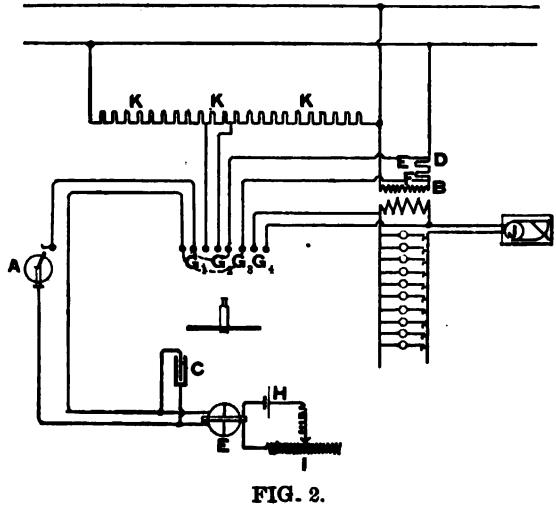


FIG. 2.

semi-circular board, etc., is mounted another piece of hard rubber, insulating and supporting the thin metallic strip, P O, that bears against the above brass rod. G and I then are the terminals of this commutating apparatus.

In Fig. 2, E F is a non-inductive resistance in series with the primary of the transformer which is at work. At A is the apparatus described in Fig. 1, and E is an electrometer reading through a wide range.

The terminals of the above non-inductive resistance and those of the electrometer are connected together through the commutating apparatus at A. Then it must be evident to all that the electrometer will become charged with a difference of potential equal

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to that existing between the terminals of the non-inductive resistance at the instant that the fixed edge on the armature passes the tip of the tongue in the apparatus at A. By reading the indications of the electrometer, therefore, and knowing the value of the non-inductive resistance E F, the value of the primary current corresponding to the particular phase due to the position of the arm in the apparatus at A becomes known. In a similar manner the primary and secondary E. M. F. are observed by changing the connections accordingly at $G^1$, $G^2$, $G^3$, $G^4$. Then the arm is rotated to another position, corresponding to a different phase, and the corresponding values of E. M. F's and current again observed as before. In this manner we proceed at equal intervals, sufficiently near, so that a curve may be determined by the values thus observed at the several intervals, so that the values of the E. M. F's or currents shall be accurately known at all times throughout a complete period.

A few words with regard to the electrometer at E, are not out of place here. It is the form that the writer devised especially for this and similar purposes. The essential features for an electrometer for these purposes are that it shall have the widest possible range through which it will read with accuracy. Its indications must be unvaried by the absolute potential to which it is subjected as a whole. Its law must be perfectly definite, and it is also desirable that its constant be unchanging.

Fig. 3 illustrates this instrument in diagram. It consists essentially of cylindrical electrometer needle and quadrants E. D. To the upper side of the electrometer needle is attached a magnetized steel mirror that acts as a magnet and as a mirror for observing the position of the same. The needle is hung by a single silk fibre, H, from a hook in the top of the case, as shown. Metallic contact from the needle to the case is made by means of a platinum wire, .0002 inches in diameter. This wire is readily provided in the desired form by using the platinum cored silver wire that is supplied by makers of surveying apparatus. It is cut the desired length, and hooks bent into shape at its terminals. By immersing all of it but the hooked terminals in nitric acid, the silver is dissolved away leaving the fine platinum core terminated by the two silver hooks. One end of this platinum wire thus prepared is linked into a hook into the top of the electrometer case and the other end into a small ring formed by a twist of the

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aluminum wire that surrounds the mirror C. The electrometer case is circular and the above needle and quadrants are arranged so that the magnetized mirror is at the centre of the case, and the needle and quadrants below it. About the case, as the figure indicates, is wound a coil, B B, of rather fine insulated copper wire. The magnetic mirror and this coil then, when the latter is in the magnetic meridian, constitute an arrangement similar to that of a tangent galvanometer. In the electrometer, the needle, case, and one set of quadrants are connected together and form one ter-

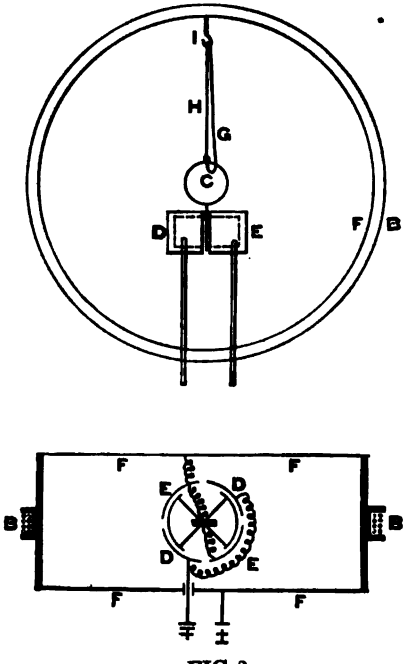


FIG. 3.

minal and the other set of quadrants, being connected together form the other terminal of the instrument, in the manner set forth in the diagram. Thus then, when the electrometer terminals are subjected to a difference of potential, the needle is acted upon by a couple brought about by the electrostatic forces and is deflected from its position of equilibrium. Then, as is shown in Fig. 2, current from a gravity cell in circuit with a suitable rheostat is sent through the coil on the electrometer in such a direction that the needle is brought toward its zero position by the action of the coil, carrying the current, on the magnetized

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mirror. The current is then further adjusted till the needle stands balanced at zero under the mutual action of the electrostatic and the electromagnetic forces. Under such circumstances then the difference of potential is proportional to the square root of the current.

If we can, as was the case when the measurements here presented were made, consider the E. M. F. of our cell constant, the difference of potential is likewise proportional to the square root of the reciprocal of the total resistance in circuit with the cell. Parallel readings, taken with a standard voltmeter throughout a range varying from 3 to 600 volts, gave identical results showing no deviation from the above law and an unvarying constant. On account of the metallic case and its connection to the rest of the apparatus, the indications of the electrometer are so far as could be observed, entirely independent of the absolute potential to which it is subjected as a whole. In Fig. 2, when contact was made at A, and the electrometer charged to the potential difference to which its terminals were then subjected it was found that considerable of the charge was dissipated by leakage during the course of a revolution of the armature, no matter how good the insulation of the apparatus was. A one-half microfarad mica condenser was then placed in multiple arc with the terminals of the electrometer at C. Then after a few revolutions of the armature the condenser became charged to precisely the same difference of potential existing at the terminals of the electrometer D B, as shown in Fig. 2, when the rotating edge on the armature passed the tip of the tongue on the arm at A.

Under these circumstances the leakage that occured was entirely unobservable as compared to the charge in the condenser during the course of time required for the armature to make many revolutions. Thus arranged then the electrometer would give accurate readings of the primary and secondary E. M. F.'s and primary current corresponding to the connection of its terminals and the position of the arm at A. Again, the square root of the mean square of any of these values could at any time be read from the electrometer by short-circuiting the apparatus at A, and cutting out the condenser at C. For the purpose of obtaining the curve of impressed E. M. F. and the $\sqrt{\text{mean}^2}$ of the same, twenty-two 50 volt lamps were put in series across the primary circuit. The $\sqrt{\text{mean}^2}$, of the impressed E. M. F. in the primary was then obtain-

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ed by reading, by means of the electrometer with the condenser cut out and the commutating apparatus short circuited the $\sqrt{\text{mean}^2}$ difference of potential existing between each set of two lamps. In this way 11 readings were obtained, the sum of which was the total impressed E. M. F. This served as a calibration of the non-inductive resistance formed by the lamps. At the same time that these observations were made, two lamps were determined upon to be used in all subsequent observations on the total E. M. F. The above observations served then as a calibration for the indications of the two lamps thus to be used. For the constant obtained by the ratio of the above total E. M. F. to the E. M. F. of these lamps taken at the same time always served to deduct the total $\sqrt{\text{mean}^2}$ or any particular value corresponding to a particular phase of the impressed primary E. M. F. when the same had been

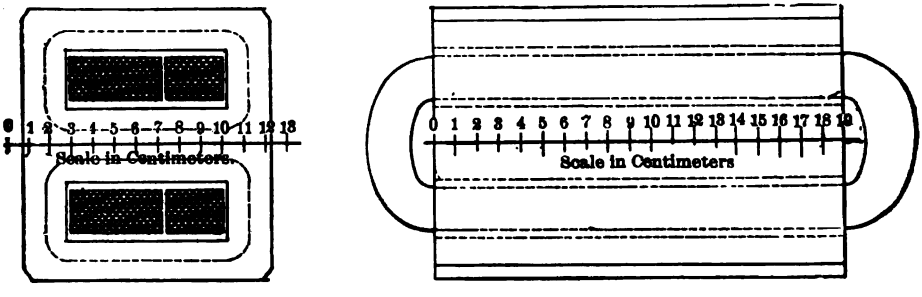


FIG. 4.

observed with regard to the two lamps in the group thus set apart. In this way we avoided the direct measurements of the total impressed E. M. F.

Two 50 volt lamps, E and F, were placed in series with the primary for a non-inductive resistance, and, as previously stated, the $\sqrt{\text{mean}^2}$, and the values corresponding to any particular phase of the fall of potential through these lamps were observed. This gave a measure of the $\sqrt{\text{mean}^2}$ or any particular value corresponding to a particular phase of the primary current, when the resistance of these lamps was known at the temperatures to which they were brought by the current. A curve of resistance corresponding to the range of currents through which we used these lamps was determined carefully by Mr. Merritt, at the Cornell magnetic observatory.

In series with the secondary circuit was placed a gravity am-

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meter containing a few small turns, and correct in its adjustment. It indicated the $\sqrt{\text{mean}^2}$ in the same way that an electro-dynamometer would have done. The observing of the various values of the secondary E. M. F. required no special arrangement—this was done direct in all cases. Since the secondary was always at work on a circuit possessing almost no inductance, no determinations of the curve of secondary current were made, for it would be found to be so nearly in unison with the secondary E. M. F. and possess all the characteristic variations of the same. The $\sqrt{\text{mean}^2}$ of its value was always known from the indications of the ammeter. As a load for the transformer ten 16 c. p. 50 volt lamps were provided that could be turned on and off as desired, and they were at an average distance from the transformer of not more than five feet

$G^1$, $G^2$, $G^3$, $G^4$, represent, in figure 2, the various terminals conveniently arranged on a switch-board for ready adjustment for any desired set of connections. The adjustable resistance at I, consisted of a plug resistance box, enabling one to get any number of ohms in circuit from 100,000 down. It was very conveniently arranged; but a suitable slide rheostat and a dampened magnet on the electrometer needle would have greatly facilitated the rapidity with which observations could be taken. The mode of procedure was to set the brush at some suitable point of starting out, then corresponding to this point readings of the instantaneous values of primary E. M. F. were made. When lamps were turned on in the secondary, the ammeter in that circuit was also read. The brush was then moved forward to a new position and the above readings repeated. This was continued until we had gone over a complete period of two alternations, then the $\sqrt{\text{mean}^2}$ readings of the primary and secondary E. M. F.'s and primary current were made To do this required a period of time covering usually not more than two and one-half hours. Careful observations were made which showed that the insertion of one, two, or three lamps in the primary circuit *did not perceptibly change the relation* of the primary E. M. F. and current and secondary E. M. F. The indications of the ammeter gave data for correcting for variations of the speed of the dynamo, that throughout was not great.

The following data should be given with regard to the transformer that was used by us :—

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| | |
|---|---|
| Number of turns in the primary coil | 675 |
| " " " secondary coil | 35. |
| Resistance of the primary | 21.8 ohms. |
| Resistance of the secondary | .04 " |

Fig. 4 is furnished with a scale to which it was drawn, so that from it any details as to dimensions of the transformer can be obtained.

The iron discs of the magnetic circuit of the transformer were made one-half millimeter in thickness, their surfaces merely oxidized, so that no special insulating material was provided between the laminations. The total volume of laminated iron used in the transformer was 2,050 cubic cms.

The mean cross-section of the magnetic circuit was 63.3 square cms., and the mean length of the magnetic circuit 30.8 cms.

The following observations with the secondary on open circuit and working on one lamp, five lamps, and 10 lamps were made and have been plotted in Figs. 5, 6, 7 and 8. The corresponding curves located by them, drawn in by the scales designated.

*Secondary on open circuit.*

(See Fig. 5.)

| Brush reading. | Primary. E. M. F. | Current. | Secondary. E. M. F. |
|---|---|---|---|
| 21 | 119 | .20 | 5.5 |
| 20 | 855 | .05 | 62.7 |
| 19 | 1250 | .07 | 63.4 |
| 18 | 1420 | .11 | 70.7 |
| 17 | 1330 | .14 | 66.8 |
| 16 | 900 | .19 | 46.0 |
| 15 | 45 | .21 | 00.0 |
| 14 | 751 | .04 | 37.8 |
| 13 | 1210 | .08 | 62.0 |
| 12 | 1390 | .12 | 72.0 |
| 11 | 1410 | .15 | 72.5 |
| 10 | 1100 | .18 | 57.8 |
| 9 | 355 | .21 | 14.5 |
| 8 | 645 | .08 | 32.3 |
| 7 | 1130 | .04 | 57.8 |
| Observed $\sqrt{\text{mean}^2}$ | 1025 | .14 | 54.5 |
| Calculated from curves $\sqrt{\text{mean}^2}$ | 1030 | .147 | 53.5 |

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*Secondary closed through one lamp.*

Secondary on Open Circuit.

(See Fig. 6.)

| Brush reading. | Primary. E. M. F. | Current. | Secondary. E. M. F. |
|---|---|---|---|
| 28 | 605 | .225 | 31.4 |
| 27 | 330 | .125 | 15.3 |
| 26 | 917 | .048 | 45.2 |
| 25 | 1300 | .179 | 67.6 |
| 24 | 1403 | .215 | 71.7 |
| 23 | 1300 | .235 | 67.1 |
| 22 | 820 | .239 | 43.8 |
| 21 | 132 | .185 | 4.7 |
| 20 | 835 | .000 | 3.9 |
| 19 | 1238 | .151 | 61.5 |
| 18 | 1420 | .215 | 71.7 |
| 17 | 1363 | .238 | 68.4 |
| 16 | 1026 | .246 | 52.7 |
| 15 | 170 | .215 | 9.7 |
| 14 | 793 | .048 | 35.6 |
| Observed $\sqrt{\text{mean}^2}$ | 1053 | .196 | 52.3 |
| Calculated from curves $\sqrt{\text{mean}^2}$ | 1021 | .190 | 51.4 |

Mean of ammeter readings.....1.26

*Secondary closed through five lamps.*

(See Fig. 7.)

| Brush reading. | Primary E. M. F. | Current. | Secondary E. M. F. |
|---|---|---|---|
| 29 | 956 | .449 | 40.3 |
| 28 | 41 | .250 | 10.4 |
| 27 | 723 | .000 | 28.9 |
| 26 | 1194 | .356 | 54.8 |
| 25 | 1447 | .495 | 69.1 |
| 24 | 1350 | .483 | 67.2 |
| 23 | 1103 | .453 | 57.6 |
| 22 | 293 | .304 | 21.5 |
| 21 | 560 | .000 | 19.8 |
| 20 | 1110 | .318 | 48.8 |
| 19 | 1383 | .464 | 65.7 |
| 18 | 1429 | .511 | 70.0 |
| 17 | 1228 | .500 | 60.3 |
| 16 | 567 | .374 | 24.0 |
| 14.7 | 585 | 0.030 | 23.4 |
| Observed $\sqrt{\text{mean}^2}$ | 1050 | .390 | 51.0 |
| Calculated from curves $\sqrt{\text{mean}^2}$ | 1036 | .383 | 50.6 |

Mean ammeter reading.....5.83

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*Secondary closed through ten lamps.*

(See Fig. 8.)

| Brush reading. | Primary E. M. F. | Current. | Secondary E. M. F. |
|---|---|---|---|
| 21 | 138 | .242 | 5.2 |
| 20 | 826 | .276 | 29.7 |
| 19 | 1237 | .642 | 53.5 |
| 18 | 1378 | .795 | 64.0 |
| 17 | 1300 | .821 | 64.3 |
| 16 | 924 | .700 | 51.1 |
| 15 | 63 | .340 | 15.0 |
| 14 | 698 | .188 | 23.7 |
| 13 | 1138 | .587 | 49.0 |
| 12 | 1370 | .810 | 63.7 |
| 11 | 1343 | .844 | 66.0 |
| 10 | 1073 | .771 | 26.5 |
| 9 | 323 | .479 | 26.5 |
| 8 | 590 | .000 | 17.0 |
| 7 | 1117 | .538 | 42.8 |
| Observed $\sqrt{\text{mean}^2}$ | 1040 | .631 | 49.3 |
| Calculated from curves $\sqrt{\text{mean}^2}$ | 1020 | .634 | 49.3 |

Mean ammeter reading.....10.65

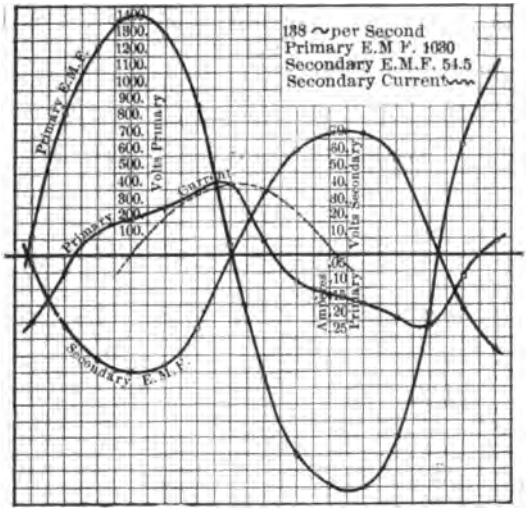


FIG. 5.

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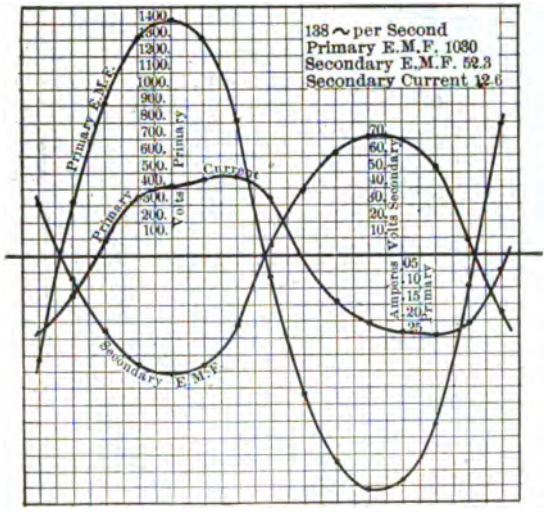


FIG. 6.

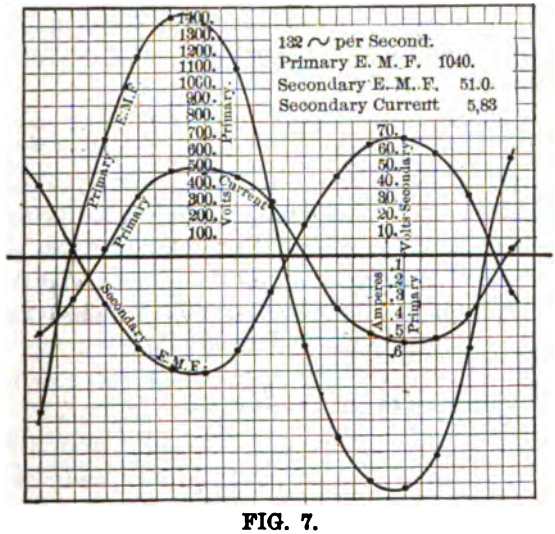


FIG. 7.

In Fig. 9 are plotted curves deduced from the foregoing observations, that show clearly the rate at which energy is given to the transformer, or that the transformer restores to the circuit at all points of a complete alternation for the several conditions

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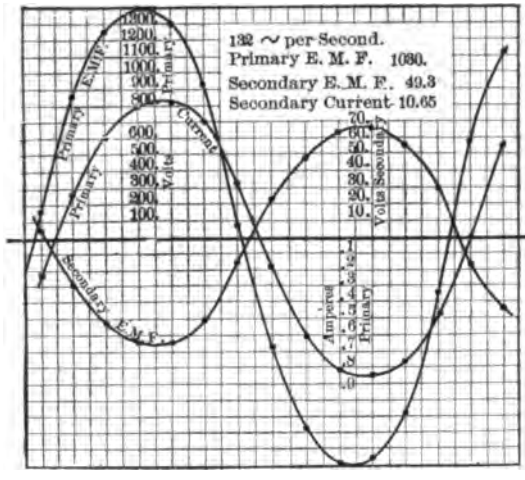


FIG. 8.

under which the transformer was operated. The curves themselves show so clearly this particular part of the performance of the transformer that nothing more need be said about them, except to give the percentages of the work given to the transformer that is restored to the circuit by it under the several foregoing conditions:—

Open circuit.....6.8%
One lamp.....3.9%
Five lamps.....96%
Ten lamps.....86%

The above observations and data are ample wherewith to compute the various losses of energy that take place in the transformer under the several loads and under no load, and the deduction of the corresponding efficiencies. These values have been computed and are given in the following table.

Proper corrections have been applied for the two lamps in series with the primary of the transformer.

| Secondary E. M. F.* | Primary watts. | Secondary watts. | Efficiency. | Total loss in watts. | Hyster. loss in watts. | Heating loss. Primary watts. | Heating loss. Secondary watts. |
|---|---|---|---|---|---|---|---|
| Primary.....10.20 | | | | | | | |
| Secondary, open 52.3 | 96.1 | 0.0 | 0.0 | 96.1 | 95.7 | 0 4 | 0.0 |
| One lamp.....52.3 | 159.1 | 64.3 | 41.1% | 94.8 | 93.9 | 0.9 | 0.0 |
| Five lamps.....50.1 | 388.6 | 300.9 | 77.5% | 87.7 | 83.1 | 3.3 | 1.3 |
| Ten lamps.....47.5 | 607.9 | 525.0 | 86.6% | 82.9 | 69.7 | 8.7 | 4.5 |

* The values given in this column have not been corrected for the two lamps in series with the primary for the first three conditions and the one lamp that was used for the last. With 10 lamps, where one lamp was used in the primary this correction amounts to an increase of the secondary E. M F. of three per cent. On open circuit and one lamp it is negligible and three per cent. increase for five lamps. When this correction is applied the drop of 3.5 volts obtained is what was observed by direct measurement on the secondary.

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In Fig. 10 these values have been plotted to scales there indicated, and the respective curves that they determine have been drawn so that one can plainly see the exact performance of the transformer under all loads.

It is interesting to note that this transformer might be loaded to twice its rated capacity and the heating of the coils would still be less than that of the iron, although the heat produced by the iron grows less as the load comes on. Likewise, that its efficiency would not yet have reached its maximum and that it would have a value of 92 per cent. In Fig. 11 the outer curve represents the relation between the magnetizing current in the primary and the degree of magnetization for all points of a complete cycle. The values locating the curve expressing this relation were readily deduced from the observations made when the transformer was working on open circuit. In Fig. 5 the dotted curve represents the curve of primary current that would be found, should Foucault currents be known to be absent, and the relation of ampere turns and magnetization be the same going up as coming down. Then if Foucault currents were present the dotted curve would have a component at a quarter of a period in advance. This would produce a negative lag in the dotted curve. From the position of the actual primary current, it is plainly seen that but a very small component of the above nature is possible, and that the energy that is wasted by eddy currents must therefore be small. The radical departure of the primary exciting current from the approximate sinuous variation of the primary impressed E. M. F. is plainly brought out to be due to *hysteresis*. From the preceding consideration it is also evident that almost the entire advance of the exciting current and, therefore, the corresponding dissipation of energy, is due to the same cause.

It was thought of much interest to see what amount of hysteresis should be indicated by carrying the transformer slowly through the same cycle of magnetization that it went at the rate of 138 cycles per second when at work on the circuit with its secondary open. Accordingly, by Ewing's method modified for the purpose by Dr. Sumpner, Mr. Merritt determined the inner curve shown in Fig. 11. We regret greatly not to have had time for a careful redetermination of this inner curve, and to carry the magnetization to the same maxima that was done in the transformer when on the circuit. The agreement between the cards would have been more marked even than in Fig. 11.

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The assumption made by Mr. Swinburne in his remarkable and valuable paper on the "Design of Transformers" (proceedings of the British Association, 1889), would therefore, be fully substantiated. Mr. Mordey's experiments, in which *hysteresis* and *Foucault current* losses producing a common loss was determined, were performed by cycles of magnetization produced by rotation in which the degree of magnetization did not vary in amount but direction, and cannot be said to throw light on the correctness of Mr. Swinburne's assumption. Some, commenting on this paper, have used Mr. Mordey's results as evidence that these assumptions are wrong.

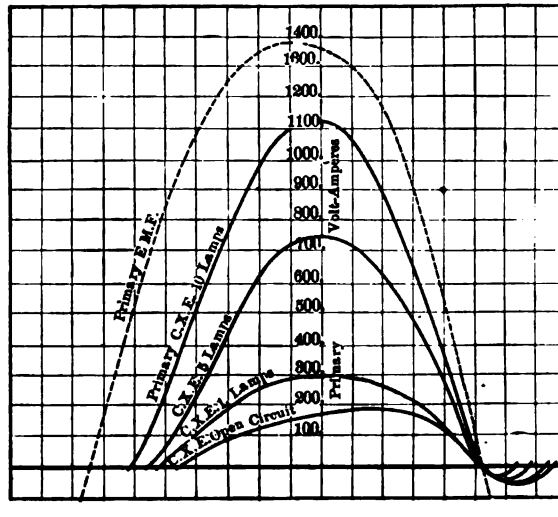


FIG. 9.

By a knowledge then of the magnetic properties of the iron, with which a given transformer is to be built, and the methods made use of by Mr. Swinburne, its efficiency is something that can be correctly predetermined.

The importance of making a transformer produce the same E. M. F. at the terminals of the secondary under all loads, asserts itself when it is used for incandescent lighting. In the transformer, under consideration from the ratios of the primary and secondary turns, the E. M. F.'s that they produce, and the variations of magnetization that had to take place through the primary, in order that the same should produce an E. M. F. equal and opposite to that of the primary impressed E. M. F., the mag-

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netization produced through the secondary and the magnetization set up about the primary in its own air space are determined. In the present transformer this "leakage" of magnetism amounted to about 1.2 per cent. When the transformer works on full load, 4.5 times as much current passes through the primary, and the "leakage" of the primary in its own space is 4.5 times as much as on open circuit and becomes 5.4 per cent. This value, together with the small drop due to the actual resistances of the transformer coils, accounts for the fall of 3.5 volts that was observed by turning on all of the ten lamps.

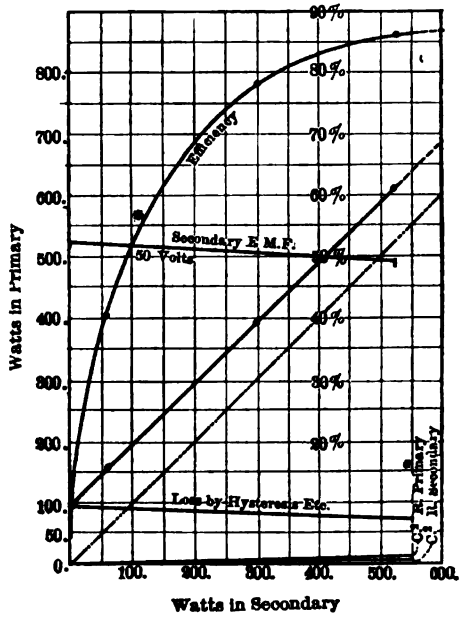


FIG. 10.

Attention might be called to a similar "leakage" in magnetism that takes place in the secondary circuit. It is plainly brought out in Fig. 8 by the lag of the secondary E. M. F. This magnetic "leakage" producing a self-induction is proportional to the secondary current. The rate of change of this quantity then is proportional to the E. M. F. that it produces. This E. M. F. is, therefore, a quarter of a period behind the secondary current, and results in producing a small lag in primary and secondary currents and secondary E. M. F.

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Finally, there is a curious behavior of this transformer that remains to be accounted for. This is the considerable decrease in the loss of hysteresis as the transformer is loaded down, that is not to be accounted for by rise of temperature or the falling off of the magnetization due to the increased "leakage" about the primary in its own air space.

The following reason suggested itself to the writer, why this should take place:—

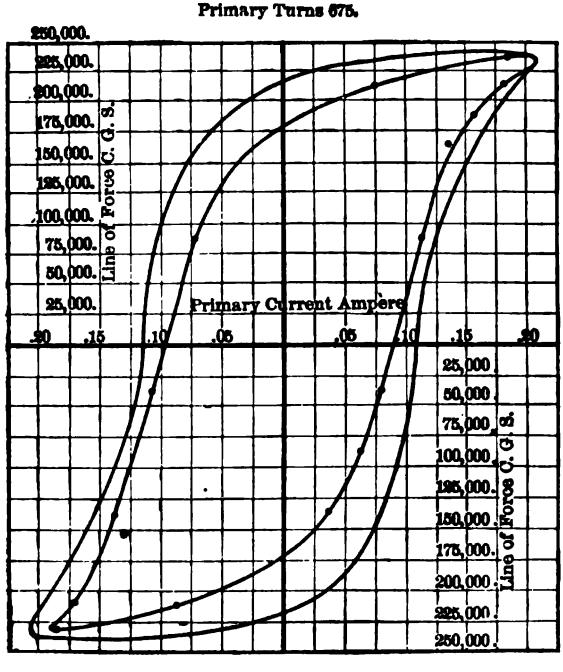


FIG. 11.

Mechanical shock has been shown to greatly reduce loss by hysteresis when iron is passed through cycles of magnetization. Since the currents are at all times opposite each other in the two coils of a transformer, strong repulsion occurs when these currents are at a maximum and no force is exerted when they pass through zero. So it follows that they continually keep thrusting each other apart when at work and add to the disturbance of the laminated iron that already exists on account of its changing magnetization. This increasing of the mechanical vibration of

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the iron, may therefore account for the above-mentioned phenomenon.

On open circuit the maximum magnetization of the iron per square cm. was 3,850 C. G. S.

Loss by hysteresis per cycle per cubic cm., neglecting Foucault currents, .046 watts at 138 $\sim$ per second.

Coercive force per centimetre of the iron, 2.76 C. G. S.

In conclusion, the writer would say that the data here given show for themselves so clearly the advisability of providing some practical means for breaking the primary circuit of the transformer when not in use, that the strong advice of Mr. Swinburne in concluding his paper need not be repeated.

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DISCUSSION.

MR. TOWNSEND WOLCOTT:—Did I understand Professor Ryan to say that the loss of energy is necessarily less where there is mechanical vibration?

PROFESSOR RYAN:—It seemed to us to have been so in this transformer; but we are not sure of it.

MR. WOLCOTT:—On the supposition that it is so, where does the energy come from? The idea is that the reversal of polarity of the iron absorbs a certain amount of energy in any case; is it not?

PROFESSOR RYAN:—The idea, I suggest, amounts to this: that the energy that was taken up in shocking that iron was less than what was saved in the hysteresis. That is, the hysteresis was made less by a greater amount than the energy that was spent in shocking the iron.

MR. WOLCOTT:—That is the way I understood it; but is there any explanation why that should be so?

PROFESSOR RYAN:—Not that I know of. I have not thought of the matter to any great extent, or further than I have indicated.

MR. NIKOLA TESLA:—Professor Ryan has said that the form of the primary current wave departed considerably in certain conditions, from that of the primary electromotive force; and he also stated to what he thought this departure due. I think that this departure of the primary current wave from that of the impressed electromotive force is due, to a considerable extent, to the conditions of the secondary circuit of the transformer, and I regret that Professor Ryan has not shown in the secondary an inductive resistance instead of the lamps. I think that then there would have been found a still greater departure of the primary current

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from the primary electromotive force. If we close the secondary circuit through a non-inductive resistance, such as lamps, it diminishes the lag of the primary. If we close it through an inductive resistance it increases the lag of the primary In this way two effects may be produced; first, the primary current wave will depart more or less from that of the electromotive force; second, the secondary electromotive force will lag behind the primary electromotive force, as Professor Ryan has found.

PROFESSOR RYAN:—I would like to ask Mr. Tesla how he would produce that inductive resistance in the secondary circuit?

MR. TESLA:—When you close the secondary circuit through the resistance suppose that you put a coil of wire in the circuit instead of the incandescent lamp.

PROFESSOR RYAN:—Would you not be increasing the hysteresis effect in that way? It seems to me that then just what you say ought to follow. Of course it should be understood that stress is laid merely on the fact that there is a certain component at all times flowing to keep up the magnetism; but, aside from that, whatever current passes is merely the opposite of that which passes the secondary circuit?

MR. TESLA:—You sttud that this departure was due only to the hysteresis.

PROFESSOR RYAN:—Suppose that you use hysteresis in the secondary circuit, and thereby augment the irregularities of the primary circuit; is it not, after all, ultimately due to the hysteresis?

MR. TESLA:—But suppose instead of the incandescent lamp you use a coil of inductive resistance, which would take the same current as the lamp?

PROFESSOR RYAN:—When you use any device by means of which you introduce hysteresis in a secondary circuit, do you not greatly augment the displacement of the primary current?

MR. TESLA:—Of course, as we load the secondary with lamps the primary comes closer and closer to where it ought to be; and I think if you had made a trial with an inductive coil in the secondary circuit instead of the lamps it would have shown some interesting conditions. I believe Professor Ryan stated that the secondary electromotive force commenced at a given point to lag behind the primary electromotive force?

PROFESSOR RYAN:—Of course it is gradual.

MR TESLA:—Have you not noticed, for instance, when this takes place, that it began suddenly?

PROFESSOR RYAN:—No; I have not noticed that it began suddenly.

MR. TESLA:—I should say that when the secondary circuit has a different retardation from that of the primary circuit, then this condition begins. That is to say, if you have a primary coil, and you pass the current through that coil, and you have the second-

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ary circuit closed, you then observe a certain lag of primary current. Now, if you add in the secondary circuit an inductive resistance, you can cause a still greater retardation in the primary. And if you diminish the retardation of the secondary, by inserting lamps, you diminish the retardation of the primary circuit to a greater extent than that of the secondary; thus in both cases causing the secondary electromotive force to lag behind the primary.

PROFESSOR RYAN:—I would like to say that Mr. Merritt and I intend to continue our work in this line, but, of course, we wish to vary the circuits upon which we experiment. As soon as we have done this work on the transformers we expect to take up the action of the condenser in all its relations to circuits possessing inductance, and to circuits not possessing inductance; and will test this matter which Mr. Tesla has just spoken of by working a coil in the secondary circuit, instead of a lamp. I think that a great deal is to be brought out in this way; and that one would be able, by careful study, to predict fairly well what would take place by varying the conditions.

MR. A. E. KENNELLY:—The question of hysteresis is of very great importance from every point of view. We know that we can measure the amount of energy which a converter absorbs in a given time; and we can measure also the amount of energy that it delivers during the same interval. We have then to deal with the remainder of energy absorbed by the converter uselessly; and this is to be found, first, in a purely frictional resistance to the current, whereby the energy is transformed into heat; and second, in the effect of the magnetism there is in the current producing the magnetic lag and eddy currents. It is of the very highest importance that we should be able to separate those two forces; and the paper before us gives very important suggestions by means of which we can carry that differentiation into effect. The Foucault currents can be reduced sufficiently by diminishing the cross-section of metal at every point; and we know that in good transformers such currents can be reduced to a minimum; but what we do not know is the quantity of energy which is being absorbed in the hysteresis under the conflicting conditions which are perpetually occurring.

In mechanical engineering we are brought face to face with the wonderful fact that a very large portion of its application and design lies in the general knowledge of the properties of the molecules of iron in the different conditions where iron is used; and the mystery grows when we remember that in electrical engineering it is not so much the molecular properties of iron, in the mechanical as in the electrical sense, which concerns us, and which vary perpetually in every design for apparatus; because, after a piece of apparatus has passed from the stage where the wonder is no longer new, then the question comes: How much

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can we economize and save out of a given mass of iron and copper? And the question, which is coincident with that, of how much we can save of hysteresis in iron becomes of greater and greater importance.

In hysteresis we have two distinct things to deal with; first, we have the fact that the iron will not return immediately to its previous condition after some magnetic effect has been impressed upon it; and, secondly, that it has a frictional resistance, and cannot instantly obey the reversed force. In all slow working transformers, in all pieces of apparatus where the changes are slow and steady, we can generally neglect what is called the frictional hysteresis due to speed, and simply deal with the static hysteresis; but it becomes of the very greatest importance that we should be able to distinguish more clearly the statical hysteresis from the frictional hysteresis. With regard to the question asked as to the effect of mechanical shocks on hysteresis, I think I may suggest a possibility, namely, that it is simply a question of how the magnetism which has been left after a given impulse can be shaken out; and if you can shake that residual magnetism out by any means you will have that loss by hysteresis destroyed. If you will study the hysteresis chart before us you will see that the area of the curve represents actually the amount of energy which is being consumed or delivered per cycle in the iron through its residual magnetic effect; and if you can prevent that taking place the lag would disappear.

I think the question of the differentiation of the frictional hysteresis from the static hysteresis is one which is well within the reach of experimental methods, and has become one of very great importance; and if words were necessary to recommend its importance still further, is it not enough to consider that apart from practical considerations, it has also a very important scientific bearing; because, by the way in which magnetism acts upon iron (the most completely magnetic substance we find in nature) the more readily can we guess at the principles which underly the whole phenomenon of magnetism; and the more completely can we discriminate the different conditions under which that iron acts, the more truthfully shall we be able to guess at the conditions which nature imposes upon that iron.

Dr. Wm. E. Geyer:—I would like to ask Professor Ryan (if he will be kind enough to turn to the chart showing the primary electromotive force) if any peculiarity was ever noticed about half way up in the curve of the primary electromotive force; a sudden departure from the smooth curve.

Professor Ryan:—Yes; as I think of it now.

Dr. Geyer:—Last May and June there was made, under my general supervision, a very similar experiment, where, however, we used a condenser, and discharged the condenser through a galvanometer, and in that way measured the relative dimensions

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of the electromotive force. We also got curves which were very smooth indeed (we took points more numerous than those that are drawn on the chart before us), until we got to a point about half way up, where we obtained results which at first were thought irregular and accidental. We skipped that part of the curve and went further up, when again it was extremely regular, until we got down on the other side to about the same height, where again the irregularity began. The irregularity was so persistent that it meant to my mind that it was not a simple accident of the experiment. We then took especial pains to determine points extremely near together just in that region, and persistently obtained a very decided jog in the curve; that is, a sudden upward motion, and a sudden downward motion, at the end of which the perfect regularity of the curve was resumed; and on the other side again there was the same irregularity, and the same jog on the descending curve. I have not found any satisfactory explanation as to the cause of it. If any could be offered by any one present it would be very interesting. I might mention in addition that when these same curves were determined on an open circuit, or on a non-inductive resistance, the irregularities were not noticed. They were only noticed when the transformer was a part of the main circuit.

MR. TESLA:—May I ask whether the machine was run at a constant number of alternations all the time?

DR. GEYER:—The machine was run at constant alternations—the regular commercial speed.

MR. TESLA:—I think if the number of alternations had been varied, greater irregularities would have been observed. I think it will be found that if a higher number of alternations had been chosen, the irregularity would have been more pronounced, until a certain limit was reached. I have run them as high as 15,000 alternations per minute. Where the alternations were very low the irregularities disappeared; but when the same number of alternations, with a longer magnetic circuit in the transformer was employed, they would again appear. So that, as I know that the magnetic lag was varied by the length of the magnetic circuit, I assume that this was the cause of the irregularity. Mr. Kennelly has very ably, and rightly, brought up the importance of the study of hysteresis. I think this is a field in which we should all work and achieve considerable improvement; so much so that certain of my experiments have been rather surprising; and in investigating the cause of the lag of the iron we will find the experiments not only of value to investigators but of real value to us practically.

MR. JOSEPH WETZLER:—In reference to the remarks made by Dr. Geyer as to the cause of the notch in the curve, it seems to me that it might principally be due to irregularities in the nature of the field. The field poles may have different intensities over

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different parts of the surface, so that if more strongly magnetic all around the edge than at the centre they would produce an irregular field, which would cause a corresponding effect in the current produced; so that all of the curve would not be regular.

Mr. C. O. Mailloux:—I am inclined to believe that the theory advanced by Mr. Wetzler is the correct one; and I think that the notch in the curve is accounted for by the dynamo, rather than by the reaction of the converter upon the impulse. The fact is, that in a dynamo we never have a uniform distribution of the lines of force, from the very fact that towards the centre, the lines of force are more dense than in the area which is contiguous to the edges. The consequence is that when a coil is approaching the edge of the pole it is approaching a spot where the lines of force are more dense; and after it has passed that spot it finds itself in place where the lines of force are not so dense. It again meets towards the middle of the pole, a place or period where the lines are denser; and again as it comes to the outer edge, a place where the lines of force are not so dense. Now, if you bear in mind the fact that the lines of force are merely the exponents or indicators of the condition of the magnetic medium, showing that there is a highly elastic substance under great stress or tension there, then we may replace those lines of force by elastic substances; and you will find on theoretical reasoning that you would naturally expect that the action of the wire, the moment that it begins to have the current in it, would be to react upon the lines of force and displace them at that point. We know that such is the case in continuous current dynamos, but not with alternating currents. We know that the lines of force are distorted and thrown out of their course by the action of the current in the armature itself. Professor Elihu Thomson has shown by experiment that there is such a crowding effect on the lines of force that, as a matter of fact, the area of the coil, or the contour of the coil, should inclose a smaller area than the area of the pole possesses. I should imagine that the notch in the wave of the impressed electromotive force would be due to the fact that, as the current approaches, it first meets with an obstruction which is too stiff for it to bound over, and therefore immediately cuts the lines of force, creating a high tension, which produces a higher electromotive force. Then we come to a place where the field is more uniform, and consequently we get the action which we would naturally expect—a current more nearly uniform, and at a rate more in accordance with some fixed law. Then as we come to the outer edge we must pass through another crust of the lines of force, and we would naturally expect to find another big break and a slight up-wave. Pursuing the same reasoning you will find that this would take place just exactly as Dr. Geyer has found by experiment; and that the speed at which the alternations occur have a great deal of influence

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upon that. I should have expected that the lines of force, being like all elastic substances, more brittle to a rapidly acting force, would show that effect more perceptibly at higher alternations than at lower ones.

MR. TESLA:—Just a word before you pass to another subject. That opposition which was alluded to as occasioned by the dynamo machine might not have its cause in the machine; but that very kind of opposition may exist in the transformer itself; and there is where I believe it does exist. I was sometime ago engaged in some work in getting direct currents from an alternating current; and I found that I was able to produce a preponderance of current impulses in one direction over those of another; and then I found that under certain conditions an opposition appeared, exactly as was stated by Mr. Mailloux in regard to the dynamo machine; and that such conditions can be brought about; and that they depend greatly upon the iron, on the number of alternations, and the length of the magnetic circuit. Imagine, for instance, that you have in the magnetic circuit of the transformer, magnetism in one direction set up; certainly if such magnetism exist it will oppose the passage of a current of a certain direction; and in this way a certain modification of the curve would be brought about.

MR. MAILLOUX:—I am very glad that Mr. Tesla spoke of that. I might have gone farther, and said that undoubtedly the same phenomenon would occur in the transformer core itself, and that there would be changes of magnetism there under different circumstances; but inasmuch as he has so much more ably explained it than I could, I need not refer to it again. The only other point I wish to advert to is in connection with some of these curves. I would like to ask Professor Ryan whether he has taken the trouble to follow the concomitant variations of the values of the inductance; that is to say, the instantaneous values that we are supposed to get for the inductance at different variations of the electromotive force; so that we might be able to get a means of comparison between theory and practice. As we all know, the theory of the transformer is one thing, while the practice is another thing, quite remote and apart from it; so much so that the theory, although it is not yet complete, is already behind the times. We know also that that innocent looking symbol designated by L, which represents the inductance in a transformer circuit, does not happen to do so in the transformers which we use in practice. It does so on paper, and in mathematical equations, and also in transformers which have no iron. Now it would have been quite interesting if Professor Ryan had undertaken either to calculate or derive the value given for the inductance; so that we might from that calculate the impedance of the circuit; or, in other words, that spurious resistance factor by which we must multiply the square of the virtual current in order to get the energy that appears in the circuit.

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PROFESSOR RYAN:—If I have understood Mr. Mailloux's question I will answer it in this way: That if you take what is the accepted theory of the transformer up to date, and which assumes always. I believe, that the relation of the current and magnetism of the iron is the same in an up curve, as it is going down; taking that theory as it has been elaborated, and the suggestion made by Lord Rayleigh about a year ago, that is to say, taking the transformer and observing the relation of the magnetism of the iron corresponding to any particular number of ampere turns going up and coming down, to modify that theory (because it is not always the same), and when you have measured the difference that exists in going up and coming down, you will get exactly the state of affairs that is here found actually to exist. The suggestion that was made by Dr. John Hopkinson in a note published in the Proceedings of the Royal Society a few years ago, made a faint suggestion that if you assume the dotted curve in Fig. 5. and substitute for the same a curve as modified by the values which you obtain through *hysteresis*, you will get precisely this state of affairs brought out in Fig. 5 as observed for the primary current. One thing more with regard to the method by means of which you can express the exact shape of those curves mathematically, and therefore proceed by means of mathematical investigation, and by means of the impressed electromotive force that we have here given, to find what it is, and what should follow. I will say that Mr. Merritt has carefully analyzed the properties of those curves, and has shown that the impressed electromotive force curve is made up, in the first place of a sine curve in unison with it, and another curve of the third order running along like *this;* (indicating) of which the equation would be:

$$E_1 = 1{,}500 \sin \theta - 42. \cos \theta + 100. \sin 3.\theta + 28. \cos 3.\theta;$$

and finally one of the fifth order; and if we should carry it one further we should find with it one of the seventh order—in odd orders, the even orders having disappeared, or else the magnetism would be heavier on one side than on the other. But matters of that sort are very technical; and I did not think that these curves, representing the constituents of these various curves, would be of much interest, or I should have brought them with me.

MR. E. G. ACHESON:—I understood Dr. Geyer, in speaking of the notch in the curve, to say that he obtained it only when he had the transformer in. That being the case it can scarcely be due to the machine.

DR. GEYER:—The notches were not obtained when the dynamo was run on an open circuit.

MR. KENNELLY:—In that case, I venture to say that it must be due either to the magnetic lag or else to a variation in the self-induction. If the processes of self-induction were variable it might be expected. With such variations it is probable that such kinks would follow.

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DR. GEYER:—Am I right in understanding Professor Ryan to say that the efficiency of the transformer was 85 per cent.?

PROFESSOR RYAN:—Eighty-six and six-tenths per cent. when working with ten lights in the secondary.

DR. GEYER:—Was that efficiency tested also in some other way?

PROFESSOR RYAN:—No; it merely come in as a secondary matter.

MR. MAILLOUX:—It strikes me that Doctor Geyer knows more than he wants to tell us about the transformer tests. I have been told that some extensive work has been going on at Stevens Institute, and it would be interesting to get some information about it.

DR. GEYER:—What I could say about it has already been published in the *Journal of the Franklin Institute.* It would have been read before this Institute, except that it came late last year, in June, before the summer vacation; and there were so many other papers that it was crowded out. The other tests we made, are very much like those of Professor Ryan, except that we used a condenser as a means of measuring the electromotive force; and we worked a 20 light transformer instead of a 10-light; and the mechanism for taking off the instantaneous electromotive force was slightly different. It is hardly worth while to go through details, as a larger part would be repetition. I have not seen anything in Professor Ryan's charts that differs from those that we obtained. So far as I can see, the results are essentially of the same nature.

THE CHAIRMAN (Vice-President T. C. Martin)—I understand that Mr. Stillwell, who is Mr. Shallenberger's associate, is here, and if he is moved to speak we would be glad to hear from him before the meeting is closed.

MR. L. B. STILLWELL:—The work that Professor Ryan has introduced to-night is in the general line that we have been working on for two or three years. I had not intended to add anything to the discussion, but there is one point that I might mention which may possibly be of interest, and that is, that we have noticed the point to which Professor Ryan referred in the case of a 10-light transformer, wherein he found that the loss due to the iron decreased as the load is added to the transformer. We have observed that this decrease is more marked in the case of a small one. In a 40 light transformer the iron loss is more nearly a constant; and it seems to me that this fact is in the line of the explanation which has been suggested, as to the shaking out of the magnetism, and the consequent decrease of loss in iron at heavy load in small-sized transformers, as larger ones would be somewhat less liable to mechanical vibration

If I have understood the diagrams correctly, there is one other point which differs slightly from the observations I have made, in

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which observations, however, I used the divided electrodynamometer method of measuring the angle of lag. Of course, that method is based upon the assumption that these are sine curves. Applying that method we have found that the lag factor, or cosine, is somewhere in the neighborhood of 70 degrees; and as load is added to the secondary the factor increases more rapidly, than shown by the curves that Professor Ryan has drawn. For example, with five lights on the secondary I have found that the primary and secondary currents are practically 180 degrees apart, the cosine of the angle of lag being about 98 degrees. With that explanation the discrepancy may possibly be due to the irregularity of the primary current, as the diagram by Professor Ryan shows.

I will say that we have also quite recently adopted a method of drawing an accurate diagram of the wave E. M. F. The method is due to Messrs. Scott and Morris, of our laboratory. I have not applied it yet, and have not seen it applied to the purpose of noting accurately the form of wave derived from our ordinary machines, since we have been more especially engaged on new types and various experimental work. The method, however, would afford a very ready means of checking up this observed kink in the curve; and I shall take the trouble to make experiments as soon as possible to throw light on that point. The method in question consists simply in mounting upon the armature shaft a wooden disc with a metallic contact at one point in the periphery, this point being connected with one terminal of a voltmeter, while the other terminal of the voltmeter is attached to one collector of the dynamo. A brush that is connected with the other collector touches the metallic point on the disc once in each revolution. By altering the position of the disc we can get a potential reading on the voltmeter proportional to the electromotive force developed by the machine at any given position of the armature, and moving it gradually through 180 degrees we have obtained surprisingly accurate results—the quantity of current through the voltmeter being large and the time being very slow. The cards I have seen made out in the last week are very accurate, and show perhaps 40 points on a phase diagram. I regret that I have none of the cards here, as they might be interesting in connection with the points brought out.

I would like to add one observation, and it is with regard to the observed efficiency of the transformers. It is, of course, understood that the efficiency of a small transformer is necessarily much less than that of a large one. The conditions heretofore have been such as to compel the use of small transformers, but the tendency as we observe it is very generally towards the use of larger ones. This tendency will do away in a great measure with the implied criticism upon the efficiency of the transformer system.

DR. GEYER:—I might say that three years ago, when the then

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existing methods of measuring the efficiency of such apparatus were very uncertain, we resorted to some heroic treatment of it. We stripped the transformer of its outer coil (which I think has not much to do with its efficiency) and the whole transformer was immersed in kerosene oil, and the transformed current was also used up in a calorimeter, consisting of a jar of kerosene; and then we found that as the load was increased the proportion of heat in the calorimeter to the total heat produced, was less and less as the load was made greater and greater.

MR. TESLA:—Mr. Stillwell has alluded to a method of tracing the wave. I would like to ask the members if any of them have ever made an attempt to find out whether there is a difference when the laminated sheets of the transformer are loose or tight, and if not I wish some one in his idle hours would investigate that; because I have reason to believe that there is a difference when the sheets are tight and when they are loose. Of course, it might be due to the imperfect contact of loose sheets, which would tend to diminish or increase the circulation of Foucault currents.

Adjourned.

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&c. (July, 1889.)

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**The Electric Light at the De Beers Diamond Mine, Kimberley.** *Indust.*, July 5, p. 19.

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**New and Useful Device. The Walworth Pole and Bracket.** *Md. Lt. & Ht.*, July 11, p. 44.

**Standard Types of Apparatus.** *Lond. Elec. Engr.*, July 26, p. 75.

**The "Drop" and Size of Wire in Wiring Calculations.** G. T. Evans. *Elec. World*, July 13, p. 21.

**The Extension of Electric Lighting.** *Elec. World*, July 13, p. 26.

**Electric Energy and Light.** (Note.) *N. Y. Elec. Engr.; Lond. Elecn.*, July 5, p. 215.

**The Economies of Electric Light and Power Stations.** (Corr.) A. P. Wright. *Md. Lt. & Ht.; Lond. Elecn.*, July 12, p 254.

**Incandescent Snap Switches.** (Ed.) *West. Elecn.*, July 27, p. 42.

**Arc Light Carbons.** Louis B. Marks. *Cornell Crank; Elec. World*, July 6, p. 2; *Lond. Elec. Engr.*, July 19, p. 44.

**Notes on Electric Lighting.** E. I. Silcock. *Lond. Elec. Engr.*, July 12, p. 35; July 19, p. 51.

**The Personal Error in Photometry.** E. L. Nichols. Am. Inst. Elec. Engrs. *N. Y. Elec. Engr.*, July, p. 299.

**Where the Real Danger Lies.** *Md. Lt. & Ht.*, July 25, p. 86. (Electric Wires.)

**Fire Proof Resistance Frames.** (Ill.) *Indust.; N. Y. Elec. Rev.*, July 27, p. 3

**The Fixtures Trust.** *Lt. Ht. & Pr.*, July 18, p. 71; July 25, p. 103.

**Artistic Fittings.** (Ill.) Messrs. B. Verity & Sons. Covent Garden. *Lond. Elec. Engr.*, July 5, p. 13.

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## ELECTRIC LAMPS.

**Arc Lamps and their Mechanism.** (Ill.) S. P. Thompson. Lond. Soc. Arts. (Cont'd from p. 219.) *N. Y. Elec. Engr*. July, p. 302.

**The Efficiency of the Arc Lamp.** (Ill.) Hatsuné Nakano. Am. Inst. Elec. Engrs. *N. Y. Elec. Engr*., July, p 313.

**Arc Lamp of M. M. Perrin & Masson.** (Ill.) *Lond. Elec. Engr*, July 12, p. 29.

**Chapman and Dearing's Arc Lamp.** (Ill.) *Lond. Elec. Rev.; Elec. World*, July 27, p. 55; *West. Elecn*., July 20 p. 28.

**New Apparatus of the Schuyler Electric Company.** (Ill.) *Elec. World*, July 13, p. 23; *Md. Lt. & Ht*., July 11, p. 62.

**An Automatic Electric Reading-Lamp.** *Md. Lt. & Ht*., July 11, p. 63. (Great West. Ry., Eng.) *Lond. Elec. Engr*., July 5, p. 3.

**The Relation Between the Initial and Average Efficiency of Incandescent Electric Lamps.** (Ill.) W. H. Peirce. Am. Inst. Elec. Engrs. *N. Y. Elec. Engr*., July, p. 309

**New Incandescent Terminals.** (Ill.) *West. Elecn*., July 20, p. 36.

**Haskins' Low Lamp Guard.** (Ill.) *N. Y. Elec. Rev*., July 27, p. 8.

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## DYNAMOS, TRANSFORMERS.

**The Compound Winding Patents, King, Brown & Co.** *Lond. Elec. Rev*., July 5, p. 25; *West. Elecn*., July 20, p. 32; *Indust*., July 5, p. 15.

**Third Brush Regulation for Constant Current.** F. N. Waterman & A. C. Balch. *Cornell Crank; Elec. World*, July 20, p. 36.

**The (American) Brush Alternator.** (Ill.) *Lond. Elec. Engr*., July 26, p. 72.

**Ferranti Alternating Machines at the Paris Exposition** (Ill.) *Elec. World*, July 27. p. 48.

**The New Wood Dynamo and Regulator.** (Ill., *Elec. World*, July 27, p. 54

**A Synthetic Study of Dynamo Machines.** (Ill.) (Cont'd from p. 650.) *Lond. Elec. Rev*., July 5, p. 10; July 19 p. 64.

**The Inversions of Polarity in Series Dynamos.** M. A. Witz. *Lond. Elec. Rev*., July 5, p. 4.

**Notes on the Dynamos at the Paris Exhibition.** (Ill.) *Lond. Elec. Rev*., July 12, p. 36; July 26, p. 95

**Dynamos at the Paris Exhibition.** (Ill.) *Indust*, July 5. p. 17. (Oerlikon.)

**Exhibit of the Oerlikon Works at the Paris Exposition.** (Ill.) *Elec. World*, July 20, p. 33.

**The Efficiency of a Transformer.** T. Spencer. *Lond. Elecn*., July 26, p. 295.

**On a Shunt Transformer.** (Ill.) E. W. Smith. Lond. Phys. Soc. *Elec. World*, July 6, p. 9.

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## SYSTEMS OF DISTRIBUTION.

**Alternate Current Working.** W. M. Mordey. Lond. Instn. Elec. Engrs. *N. Y. Elec. Engr.*, July, p. 319; *West. Elecn.*, July 20, p. 36.

**Knowles Combination Electric Light System.** (Ill.) *West Elecn.*, July 20, p. 29.

**Laboratory Notes on Alternating Current Circuits.** (Ill.) W. E. Ayrton & John Perry. *Jour.* Instn. Elec. Engrs; *Lond. Elecn.*, July 5, p. 219.

**An Important Patent Relating to Alternating Currents.** *N. Y. Elec. Rev.*, July 27, p. 5. (Westinghouse.)

**The Brush Electric Company's New Alternating Current System.** (Ill.) *Elec. World*, July 13, p. 17; *Md. Lt. & Ht.*, July 25, p. 87; *N. Y. Elec Rev*, July 13, p. 1.

**The Edison Three-Wire System of Distribution.** (Ill.) W. J. Jenks. N. Y. Elec. Soc. *Elec. World*, July 20, p. 39.

**An Elementary Analysis of the Generation of Current and Potential Difference in Drum Armature Winding.** (Ill.) F. M. Weymouth. *Lond. Elecn.*, July 19, p. 273.

**On the Distribution of Continuous Electric Currents by Means of Condensers. II.** (Ill.) Stephen Doubrava. *Lond. Elecn.*, July 26, p. 294.

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## ELECTRIC MOTORS, CONTINUOUS.

**The Riker Motor.** (Ill.) *Elec. World*, July 20, p. 37.

**New Perret Motors.** (Ill.) *Elec. World*, July 6, p. 2.

**The New Detroit Electric Motors.** (Ill.) *Elec. World*, July 13, p 20; *West. Elecn.*, July 13. p 21.

**Jenney Electric Motor.** (Ill.) *West. Elecn.*, July 6, p. 3.

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## ELECTRIC MOTORS, ALTERNATING.

**Electric Motor for Alternating Currents.** Galileo Ferraris. *Bulletin International de L'Électricité; Lond. Elec. Rev.* July 19, p. 72.

**The Tesla Self-Starting Alternating System.** (Ill.) *Elec. World*, July 6, p 9; *Lond. Elec. Engr.*, July 19 p. 48; *Lond. Elec. Rev.*, July 19, p. 64.

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## ELECTRIC POWER.

**Motor in Printing Office, Providence, R. I.** *Md. Lt. & Ht.*, July 18, p 65. (Chapman & Co.)

**Motor in a Press Room.** *West. Elecn.*, July 20, p. 33 (Chicago Printing Co.)

**The C. & C. Motor in Printing Offices** (Ill.) *Elec. World*, July 13, p. 22.

**The Sperry Electric Coal Digger.** *Elec. World; Lond. Elecn.*, July 5, p 228.

**Mining Coal by the Use of Electricity.** (Ill.) *West. Elecn.; Lond. Elec. Engr.*, July 12, p. 27.

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**Electric Motor in a Hat Factory.** (Ill.) *West. Elecn.*, July 6, p. 2. (W. E. Morgan, Chicago.)

**Horse Grooming Machine Operated by an Electric Motor.** *West. Elecn.*, July 6, p. 5. (Marshall, Field & Co., Chicago.)

**Electric Pumping Plant.** (Ill.) *Indust.; N. Y. Elec. Rev.*, July 6, p. 1; *Elec. World*, July 6, p. 9. (United Elec. Eng. Co., Lond.)

**The Chretien Elevator at the Paris Exposition.** (Ill.) *Elec. World*, July 6, p. 4.

**Electric Tricycle.** *West. Elecn.*, July 20, p. 27.

**Electric Power from the Rhine.** *Md. Lt. & Ht*, July 18, p. 64.

**Good Motor Work.** Cecil P. Poole. *Elec. World*, July 6, p. 4.

**Electric Power and Storage Interests in England.** *Elec. World*, July 13, p. 21.

**Electric Yacht on the Lakes.** *West. Elecn.*, July 6, p. 3.

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ELECTRIC RAILWAYS.

**Sprague Electric Railway to Atlantic City, N. J.** (Ill.) *Elec. World*, July 27, p. 55; *N. Y. Elec. Rev.*, July 27, p. 9; *West. Elecn.*, July 27, p. 49.

**A Pioneer Electric Line Re-Organised at Binghamton, N. Y.** *Elec. World*, July 13, p. 26.

**An Electric Railway for St. Paul.** *N. Y. Elec. Rev.*, July 6, p. 3.

**Opening of Marlborough (Mass.) Electric Railway.** *N. Y. Elec. Rev.*, July 6, p. 9.

**Pullman's Electric Railway.** *N. Y. Elec. Rev.*, July 13, p. 7.

**San José Electric Road.** *West. Elecn.*, July 6, p. 5.

**Electric Railway at Rochester, N. Y.** *Elec. World*, July 13, p. 21.

**The Electric Railway at Nashville, Tenn.** (Ill.) *Md. Lt. & Ht.*, July 18, p. 66. (Thomson-Houston.)

**Electric Rapid Transit in Cleveland.** *N. Y. Elec. Rev.*, July 13, p. 10; *Elec. World*, July 13, p. 26.

**The West End Contract.** *Md. Lt. & Ht.*, July 4, p. 9; *West. Elecn.*, July 27, p. 44.

**Bentley-Knight Electric Railway Company.** (Ill.) *N. Y. Elec. Rev.*, July 27, p. 2. (West End, Boston, Mass.)

**An Interesting Achievement in Railway Engineering.** *N. Y. Elec. Rev.*, July 27, p. 1. (Burgenstock.)

**The Electric Railway at Bangor, Me.** (Ill.) *Elec. World*, July 6, p. 10; *N. Y. Elec. Rev.*, July 6, p. 3; *Md. Lt. & Ht.*, July 4, p. 18.

**The Sprague Improved Electric Railway Motor.** (Ill.) *Elec. World*, July 6, p. 3; *Lond. Elecn.*, July 19, p. 276; *N. Y. Elec. Rev.*, July 20, p. 8.

**An Improvement in Rail Construction.** (Ill.) *N. Y. Elec. Rev.*, July 20, p. 11. (White.)

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**The Short System.** (Note.) *Lond. Elec. Engr.*, July 12, p. 23.

**New Electric Car Switch.** (Note.) *Lond. Elec. Engr.*, July 5, p. 4.

**Allen Elevated Electric Railway.** (Ill.) *West. Elecn.*, July 13, p. 19.

**The Weems Electric Railway System.** (Ill.) *Elec. World*, July 20, p. 37.

**Problems in Electric Traction.** (Ill.) Louis Bell. *Elec. World; Lond. Elec. Engr.*, July 5, p. 7; July 12, p. 27; July 19, p. 53; *Lond. Elec. Rev.*, July 12, p. 46; *Lond. Elecn.*, July 5, p. 223; July 12, p. 250.

**Electric Transit in the Future.** *Boston Herald; Md. Lt. & Ht*, July 11, p. 37.

**Electric Street Railways. Comparison Between the Storage Battery and Direct Systems.** *Lond. Elec. Engr.*, July 19, p. 57; July 26, p. 76.

**Some Recent Electrical Work on the Elevated Roads, and its Bearing on the Rapid Transit Problem.** (Ill.) Leo Daft. Am. Inst. Elec. Engrs. *N. Y. Elec. Rev.*, July 6, p. 10; *Md. Lt. & Ht.*, July 4, p. 10; *Indust.*, July 12, p. 44; *Lond. Elec. Engr.*, July 27, p. 2; *Elec. World*, July 6, p. 5.

**An Opinion Regarding Telephone and Electric Railway Companies.** *N. Y. Elec. Rev.*, July 27, p. 6. (W. H. De Witt.) *Elec. World*, July 20, p. 38.

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## INSTRUMENTS, MEASUREMENTS.

**The Walker Electric Meter.** (Ill.) *Elec. World*, July 20, p. 38; *N. Y. Elec. Rev.*, July 20, p. 10.

**The Mandroux Portable Testing Apparatus.** (Ill.) *La Lumière Électrique; Lond. Elecn.*, July 26, p. 297.

**Government Standardising Laboratory.** (Note.) *Lond. Elec. Rev.*, July 26, p. 99; *Lond. Elecn.*, July 26, p. 297.

**Ayrton and Perry's Spring Ammeters and Voltmeters, and the New Hot Wire Ammeter and Voltmeter.** (Ill.) *N. Y. Elec. Rev.*, July 6, p. 6.

**The "Jolin" Pocket Galvanometer.** (Ill.) *N. Y. Elec. Rev.*, July 27, p. 10.

**A New Photometer.** (Note.) Dr. Dessendier. *Lond. Elec. Engr.*, July 26, p. 62.

**Dessendier's Recording and Announcing Photometer.** (Ill.) *Lt. Ht. & Pr.*, July 4, p. 10.

**Precautions for Safety in the Use of Sir William Thomson's Electrostatic Voltmeters in Connection with Dynamos, whether for Direct or Alternating Currents.** William Thomson. *Lond. Elec. Rev.*, July 5, p. 4.

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## UNDERGROUND WIRES.

**Board of Electrical Control.** *Elec. World*, July 6, p. 11.

**The Underground Question in St. Paul.** *West. Elecn.*, July 6, p. 4.

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**Chicago City Underground System.** (Ill.) *West. Elecn.*, July 27, p. 42.

**A Visit to Mr. Brooks of Philadelphia.** *Lond. Elec. Engr.*, July 26. p. 66.

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PRIMARY BATTERIES.

**Delany's Improved Gravity Battery.** (Ill.) *Elec. World*, July 27, p. 49.

**The Jarriant Battery Patent.** (Corr.) *Elec. World*, July 13, p. 20.

**Medical Battery and Coil.** (Ill.) *West. Elecn.*, July 6, p. 2. (Electro-Optic M'f'g Co., Chicago.)

**Primary and Secondary Batteries.** (Corr.) David Flourney. *West. Elecn.*, July 13, p. 23.

**An Improved Open-Circuit Battery.** *Lond. Elec. Rev.*, July 26, p. 100 (G. H. Bays.)

**The Germain Battery.** (Note.) *Lond. Elec. Engr.*, July 19, p. 44.

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SECONDARY BATTERIES.

**The Inherent Defects of Lead Secondary Batteries** (Ill.) Louis Duncan and H. Wiegand. Am. Inst. Elec. Engrs. *Lond. Elec. Rev.*, July 19, p. 80.

**Secondary Battery.** (Ill.) G. M. Hopkins. *Sci. Am.; West. Elecn.*, July 27, p. 42.

**Anglo-American Storage Battery.** (Ill.) *West. Elecn.*, July 27, p. 47.

**Some Results with Secondary Batteries in Train Lighting.** A. S. Brown. Am. Inst. Elec. Engrs. *Lond. Elecn.*, July 12, p. 255; *Elec. World*, July 13, p. 26; *N. Y. Elec. Engr.*, July, pp. 301–325.

**The Schoop Accumulator.** *Elec. World*, July 20, p. 33.

**Some Notes on Storage Batteries.** J. D. Dallas. *Elec. World*, July 13, p. 24.

**Automatic Accumulator Station in France.** *Elec. World*, July 27, p. 55.

**On an Experimental Theory of the Lead Accumulator.** Leonard Paget. *Elec. World*, July 27, p. 53.

**The New Anglo-American Storage Battery.** (Ill.) *Elec. World*, July 27, p. 50. (Sorley.)

**The Storage Battery Work of the Mutual Electric Manufacturing Company.** (Ill.) *N. Y. Elec. Rev.*, July 20, p. 1.

**The Knowles System of Storage Battery Distribution.** (Ill.) *Elec. World*, July 20, p. 34.

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ELECTROLYSIS.

**Initial Phase of Electrolysis.** *Jour. Chem. Soc.* (Note.) *Lond. Elec Engr.*, July 19, p. 43.

**Electrolysis of Bismuth Salts.** Alex Watt. *Lond. Elec. Engr.*, July p. 12; July 12, p. 26; July 19, p. 46; July 26, p. 68.

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**On the Limit Between Polarisation and Electrolysis.** M. H. Pellat. *Comptes Rendus; Lond. Elec. Rev.*, July 19, p. 60.

**The Hermite Electro-Bleaching Process.** (Ill.) *Elec. World*, July 6, p. 2.

**Electrical Tanning.** *Boot and Shoe Trades' Journal; N. Y. Elec. Rev.*, July 6, p. 2.

**The Electrical Treatment of Sewage.** *Eng; N. Y. Elec. Engr.*, July, p. 318.

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## THERMO-ELECTRICITY.

**On the Efficiency of Thermo-Magnetic Machines.** Charles Steinmetz. *Elec. World*, July 27, p. 48.

**Electric Heat.** Richmond, Va., *State. N. Y. Elec. Rev.*, July 13, p. 4.

**Electricity from Heat.** George D. Shepardson. *Cornell Crank; Elec. World*, July 6, p. 3.

**Thermo-Electricity Theoretically and Practically Considered.** (Ill.) I. Arthur Rust. *Elec. World*, July 27, p. 52.

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## ATMOSPHERIC ELECTRICITY.

**Lightning Conductors.** S. A. Varley. (Cont'd from p. 715.) *Lond. Elec. Rev.*, July 5, p. 8; July 19, p. 77.

**Study of the Duration of Lightning.** M. E. L. Trouvelot. *Comptes Rendus; Lond. Elec. Rev.*, July 5, p. 6.

**Lightning Conductors. IX.** O. Lodge. (Cont'd from p. 165) *Lond. Elecn.*, July 19, p. 268.

**Some Photographs of Lightning and of Black Electric Sparks.** (Ill.) A. W. Clayden. Phys. Soc. *Lond. Elecn.*, July 5, p. 227.

**Modes of Damage by Lightning.** (Ill) O. Lodge. *Lond. Elecn.*, July 12, p. 242.

**Lightning Photography.** (Ill. Corr.) Alex. J. S. Adams. *Lond. Elecn.*, July 26, p. 304.

**Some Photographs of Lightning Flashes.** F. Clayton. Phys. Soc. *Elec. World*, July 20, p. 37.

**The Glendale Lightning Arrester.** (Ill.) *Elec. World*, July 6, p. 9; *N. Y. Elec. Rev.*, July 12, p. 38.

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## MISCELLANEOUS.

**Edison Magnetic Ore Separator.** *West. Elecn.*, July 27, p. 44.

**A Permanent Magnet Ore Separator.** *N. Y. Elec. Rev.*, July 13, p. 7.

**A New Non-Magnetic Alloy.** (Corr.) J. Hopkinson. *Indust.*, July 19, p. 63.

**Tobin Bronze.** *Md. Lt. & Ht.*, July 25, p. 92.

**Important Electrical Discovery.** *Md. Lt. & Ht.*, July 25, p. 92. (William Burnley.)

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**Rapid Growth.** *Md. Lt. & Ht.*, July 18, p. 65. (Okonite Company.)

**Operating a Steam Whistle by Electricity.** (Ill.) *West. Elecn.*, July 27, p. 43.

**Electricity and Horse Racing.** *West. Elecn.*, July 27, p. 42.

**Electrical Novelties.** *West. Elecn.*, July 20, p. 35. (Detroit Electrical Works.)

**Electrical Exercising Machine.** (Ill.) *Lond. Elecn.*, July 20, p. 28.

**Electrical Specialities.** (Ill.) *N. Y. Elec. Rev.*, July 20, p. 7. (Elec. Sup. Co., Chicago.)

**Curved Electrotypes.** (Note.) *Lond. Elecn.*, July 26, p. 293.

**Electro-Photography.** *N. Y. Elec. Engr.*, July, p. 329; *Md. Lt. & Ht.*, July 11, p. 44. (Herr Korzel.)

**Automatic Photography at the Paris Exposition.** (Ill.) *Elec. World*, July 13, p. 21.

**Wire Cable Welding by Electricity.** O. K. Stuart and A. M. Bullard. *Elec. World*, July 27, p. 54.

**Hering Vice-Grip Wire Coupling.** (Ill.) *Lond. Elec. Rev.*, July 12, p. 38.

**Investigating Electricity.** *N. Y. Elec. Rev.*, July 27, p. 6. (As a Means of Execution.) *West. Elecn.*, July 6, p. 10.

**Shall Electricity Execute Our Criminals?** *N. Y. Elec. Rev.*, July 20, p. 8; *West Elecn.*, July 27, p. 47.

**A Review of Mr. Harold P. Brown's Experiments.** Ludwig Gutmann. (Corr) *Elec. World*, July 13, p. 25.

**Mr. Harold P. Brown's Reply to Mr. Gutmann.** (Corr.) *Elec. World*, July 27, p. 57.

**Is Electrical Execution a Cruel and Unusual Form of Punishment?** *Elec. World*, July 20, p. 43.

**Execution by Electricity.** *N. Y. Herald; Lond. Elec. Rev.*, July 26, p. 108.

**The Electrical Execution Investigation.** *Elec. World*, July 27, p. 57.

**Canadian Electrical Exhibition.** *West. Elecn.*, July 20, p. 29.

**The Exhibition of 1892.** *N. Y. Elec. Rev.*, July 20, p. 4.

**Columbia College School of Mines. Course in Electrical Engineering.** *N. Y. Elec. Rev.*, July 6, p. 14.

**College Notes.** *N. Y. Elec. Engr.*, July, p. 327.

**Causes of Death from Accident in New York City.** *Elec. World*, July 13, p. 26.

**Recent Actions at the Patent Office.** Wm. A. Rosenbaum. *Elec. World*, July 13, p. 23.

**Electrical Engineering at Ohio State University.** (Ill.) *West. Elecn.*, July 13, p. 22; *Elec. World*, July 20, p. 36.

**Quarterly Meeting of the New England Electric Exchange.** *Elec. World*, July 20, p. 32; *Md. Lt. & Ht.*, July 11, p. 38.

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**Electrical Conferences in Paris.** *Md. Lt. & Ht*, July 11, p. 63.

**Representatives at Paris.** *Lond. Elec. Engr.*, July 5, p. 9.

**Notes from Germany and France.** *Lond. Elec. Rev.*, July 26, p. 88.

**The Electrical Exhibition at Bingley Hall.** *Lond. Elec. Engr.*, July 26, p. 75.

**Electrical Progress in China.** *Lond. Elec. Engr.; N. Y. Elec. Rev.*, July 20, p. 1.

**Paris Headquarters of the Electric Club.** (Ill.) *N. Y. Elec. Rev.*, July 13, p. 7.

**English Address of Welcome to Visiting Engineers.** *N. Y. Elec. Rev.*, July 6, p. 8.

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**The Birmingham Electrical Exhibition.** *Lond. Elec. Rev.*, July 19, p. 79; *Lond. Elecn.*, July 26, p. 300.

**Notes of a Southern Trip.** H. E. Duncan. *Md. Lt. & Ht.*, July 18, p. 66.

**"The Cause that I Defend: 'Tis Yours, 'tis Mine."** *Lond. Elec. Engr.*, July 5, p. 6.

**A Peculiar Ground.** W. L. P. *Elec. World; Lond. Elec. Rev.*, July 19, p. 63.

**On Modern Views with Respect to the Nature of Electric Currents.** H. A. Rowland. Am. Inst. Elec. Engrs. *Lond. Elec. Rev.*, July 12, p. 51.

**Expansion with Rise of Temperature of Wires under Pulling Stress.** J. T. Bottomley. Phys. Soc. *Lond. Elec. Engr.*, July 5, p. 19; *Lond. Elec. Rev.*, July 5, p. 27.

**Electricity in Agriculture.** *Lond. Elec. Rev.*, July 5, p. 20.

**Atomic Weight of Zinc.** (Note.) *Lond. Elec. Engr.*, July 19, p. 44. (J. H. Gladstone & W. Hibbert.)

**Diamagnetism.** (Ill.) S. E. Phillips. *Lond. Elec. Engr.*, July 19, p. 46; July 26, p. 67.

**Recent Experiments of Prof. Thompson and Dr. Fleming.** *N. Y. Elec. Rev.*, July 13, p. 8.

**Accuracy in Mechanical Construction.** *Indust.; N. Y. Elec. Engr.*, July, p. 317.

**Herts's Researches on Electrical Oscillations.** G. W. de Tunzelmann. (Cont'd from p. 224.) *Lond. Elecn.; N. Y. Elec. Engr.*, July, p. 304.

**Where Shall We Place the Engineer?** Geo. H. Stockbridge. *N. Y. Elec. Engr.*, July, p. 298.

**On Free Ions.** W. Ostwald and W. Nernst. *Zeitsch. für Physik. Chemie; Lond. Elecn.*, July 26, p. 300.

**Electrical Utilization of Galvanisers' Waste Acid.** (Note.) *Lond Elecn.*, July 19, p. 267.

**The Specific Resistance and other Properties of Sulphur.** (Ill.) James Monckman. *Lond. Elecn.*, July 12, p. 252.

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**Ferro-Manganese Alloys.** B. H. Blood. *Cornell Crank; Elec. World*, July 13, p. 22.

**Studying Alternating Currents by Means of Vibrating Strings.** (Ill.) *Jour.* of Lond. Inst. Elec. Engrs.; *Elec. World*, July 27, p. 56.

**A Galvani Manuscript.** *Elec. World*, July 27, p. 56.

**Detecting Electrically the Proximity of Icebergs.** Frank R. Colvin. *Elec. World*, July 27, p. 51.

**Electromotive Force of Amalgams.** (Note.) *Lond. Elecn*, July 5, p. 214; *Elec. World*, July 27, p. 56.

**A Real Electric Plant.** *N. Y. Elec. Rev.*, July 20, p. 7. (M. Fulbert-Dumonton.)

**On the Effect of Placing a Ball and Point in a High Tension Alternating Current Circuit.** G. L. Teeple and W. K. Archbold. *Cornell Crank; Elec. World*, July 6, p. 10.

**Electrical Horse-Power Characteristics.** (Ill.) W. F. D. Grane. *Elec. World*, July 13, p. 16.

**What shall we do with our Watches?** (Corr.) *Elec. World*, July 6, p. 8.

**H. Ward Leonard.** (With Portrait.) *West. Elecn.*, July 20, p. 27.

**Charles Francis Brush.** (With Portrait.) *West. Elecn.*, July 13, p. 16.

**Obituary—Gaston Plante.** Wm. F. Swift. *N. Y. Elec. Engr.*, July, p. 331.

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**The Gardner Automatic Vertical Engine and Boiler.** (Ill.) *Elec. World*, July 6, p. 10.

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**Graphite Bearings for Pulleys and Shafting.** (Ill.) *Elec. World*, July 27, p. 56.

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**Water for Fuel.** *Md. Lt & Ht.*, July 25, p. 93.

**Ganz's Standard Screw Threads.** *Lond. Elec. Rev.*, July 5, p. 6.

**The Value of Covering Steam Pipes.** *Michigan Engineers' Annual; Md. Lt. & Ht.*, July 4, p. 18.

**Boiler Explosions and Safety Valves.** *Md. Lt. & Ht*, July 11, p. 43.

**Rope Transmission for Dynamos.** (Ill.) *West. Elecn.*, July 20, p. 28.

**Lang Automatic Water Gauge.** (Ill.) *Elec. World*, July 6, p. 10.

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# A REVIEW OF MODERN ELECTRICAL THEORIES.

BY PROFESSOR WM. A. ANTHONY.

The general phenomena of electricity are familiar to us all. As children we learned of attraction and repulsion of electrostatic charges, of condensers, of insulators and conductors, of electric currents and electro-magnets, of telegraphs, and electric fire alarms and electric bells, of the heating of conductors, and even electric lights. We have long been familiar with the effect of the current on a magnetic needle, and with the attraction and repulsion of currents for each other. We have seen that these effects are manifested at a distance from the conductors which carry the currents, and we have been willing to believe that the distances at which these phenomena could be recognized were limited only by the want of sensitiveness of the apparatus through which the effects were manifested. Probably not many of us stop to think *how* these effects were brought about. We were content with a general statement of the relations of the phenomena, or, at least, with the determination of the direction and intensity of the forces due to a given conformation of current. We talked of the attractions and repulsions as action across space, and, if we thought of them at all as requiring any mechanism through which to act, we still felt satisfied when we had discovered and formulated the laws that govern the action of these forces.

It did not matter to us that attraction across empty space was unthinkable; it was enough that action took place, and that we could measure and, to a certain extent, control it. We constructed instruments and computed forces acting under certain conditions; we multiplied experiments and thought we had developed a vast science. But there have not been wanting, even among the earlier philosophers, some who could not feel satisfied with

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the idea of action at a distance. Experience gives no clue to any explanation of action of one body upon another at a distance, except through some intervening mechanism, and if we find cases where such intervening mechanism is not apparent, to say that in these cases action at a distance is taking place, is only to say that the action is unexplained.

Gravity acts upon the distant planets, and, we believe, upon the most distant stars; but it is not enough to say that gravity acts, that it decreases as the square of the distance increases, we want to know *how* it acts. By what means or through what medium does our earth reach out to the distant planets and affect their movements? These are the questions that the dissatisfied few have asked in the past, and to-day it is not the few but the many who would be glad to have the question answered. Faraday early taught us that the mere statement of the law of electrical attraction or repulsion was no explanation, and he sought the explanation in the action in the intervening medium. He demonstrated by experiments, that have become classic, that the effect of induction depends upon the nature of the medium intervening between the conductors; a demonstration that here, at least, the intervening medium took part in the action and helped to determine the result. Magnetic and electro-magnetic phenomena were to Faraday also effects propagated through the medium; and Maxwell, following Faraday's work, subjected the whole matter to a searching mathematical analysis. It was necessary, in order to complete the theory, to assume the existence of a medium in which the forces were exerted; but, as a medium had already been assumed to account for the phenomena of light, it would hardly be scientific to assume another to account for electrical phenomena. But would not one medium suffice for electrical and optical phenomena as well? Maxwell showed how the question of the identity of the two media could be tested, and our modern views of electricity are mainly the results of his work. What do we *know* of electrical phenomena? We know that pieces of glass and silk rubbed together and then separated attract each other; that the property of attraction can be imparted to metals if they are insulated; that if two such masses of metal be connected by a wire the power of attracting each other disappears, and at the same time, the wire is warmed and for an instant exerts magnetic forces at right angles with the wire. Numerous other facts we know, but these will suffice as illustrations of the

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phenomena. When a metal conductor is discharged by touching it with a wire we say the wire carries a current, and we have been accustomed to ascribe the heating and the magnetic effects to that current. We have looked upon the thing, whatever it is, that takes place in the wire as the origin of all that takes place around it. The current warms the wire, and it confers upon it the property of acting upon magnetic needles; but *how* does it act? We cannot conceive of the action of that wire on that needle, except through something extending from the wire to the needle through which the wire can exert a push or pull. All around that wire the needle is affected; at considerable distances the effect can be exhibited, and we believe it is only want of delicacy of our apparatus that prevents our discovering it at the greatest distances. If the wire acts it acts through a medium in which it

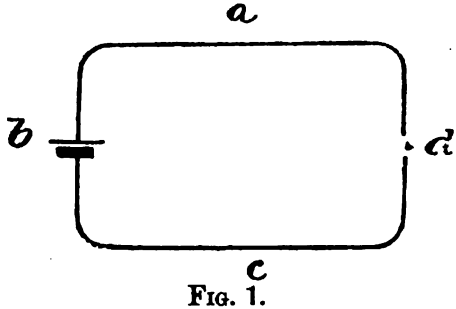


FIG. 1.

creates a disturbance, and the disturbance in turn acts upon the magnetic needle. But are we sure that the action begins with the wire? Is it not possible that the action begins in the medium, and that the wire merely separates portions of the medium and so permits action that would not otherwise take place? Maxwell has proposed a mechanical illustration of the action taking place in space when electrical phenomena occur, and Fleming and Lodge have elaborated it and brought it within the reach of non-mathematical readers. Let us suppose all space to be filled with wheels connected by idle wheels in such a way that when one turns all must turn in the same direction, except that the elasticity of the system permits a small movement of one wheel before the others in the vicinity begin to move. Electromotive force is then something that tends to turn the wheels. Let *b* in Fig. 1, represent some source of electromotive force; *a* and *c* conductors not forming a closed circuit but having an opening at *d*. The electromotive force at *b* tends to turn the wheels, but so

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long as the gap exists at $d$ the wheels are connected through all space, and the E. M. F. at $b$ can effect nothing except to turn the wheels through a small angle until the elastic resistance balances the E. M. F. In the conductor, the wheels are not supposed to be rigidly connected. They can turn by slipping on each other, and the wheels in space may turn by slipping on the wheels in the conductor; hence, as the ends of $a$ and $c$ approach each other, the connection between the wheels within the enclosure and those of outside space becomes smaller and smaller, and, when the conductors touch, there is no longer anything to prevent the wheels within from turning, and they begin to spin in obedience to the E. M. F. at $b$. The conductor is heated by the friction due to the slip of the wheels around and within it. The spinning of the wheels constitutes the magnetic forces if we assume the wheels, originally spherical, to become flattened spheroids by the spinning, and to be forced to remain in contact at their poles. Assume the wheels to have inertia, and it will require time for them to reach their full velocity, and the time will be greater as the number of wheels is greater, that is, as the magnetic forces developed are greater. On the other hand, the wheels will not at once stop if the electromotive force is removed, and if the conductor be broken at some point, allowing the rapidly spinning wheels enclosed by it to come in gear at that point with the stationary outside wheels, there will be, for a brief time, until the moving wheels can be brought to rest, a clashing and disruptive action known as the extra spark.

I have spoken of the heating of the conductor as due simply to the friction of the spinning wheels upon the wheels within the conductor. The greater the friction the greater the motion imparted to the wheels within the conductors and the greater the heating. The less the friction the less the heat, and if there were a substance whose wheels could revolve among themselves and against the wheels of space without friction, such substance would form a perfect conductor which would offer no resistance to the motion of the wheels in the space inclosed by it, and however rapidly those wheels might revolve they would have no influence to produce motion within such a conductor. We are led, then, to this, that a perfect conductor, instead of being a substance in which any E. M. F. produces an infinite flow of electricity, may be a substance in which no effect whatever is produced.

I do not present this as representing the real activities involved

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in electrical phenomena, or as a theory by which all electrical phenomena may be explained. I give it as bringing prominently into view the activities in the medium surrounding the conductor; whereas, the language in which we usually describe electrical phenomena points to the conductor itself as the seat of the electrical forces. Whatever our theory, we know that something does take place in the medium that surrounds the conductor. We know that were a heavy current to flow through a conductor in the most distant part of this room a delicate needle here on the table would show that a magnetic field was produced here. We are certain that magnetic lines of force from the electric currents on our streets, whether overhead or underground, permeate this room, and traverse our bodies even, though we have no sense through which we can become directly conscious of them. Take in your hands two wires connected to the poles of a battery or dynamo and touch their ends together. You see a flash of light, the wires become warm, they attract iron filings; coiled into a spiral they will attract with great force large masses of iron; two such spirals will attract or repel one another. What more natural than to say: Here in the wire is a new activity which warms it and confers upon it magnetic properties? What more natural than to forget or fail altogether to recognize the activities in the space around; activities that do not impress any of our senses; that do not wrench our arms, or burn our flesh, or blind our eyes; and yet it is well to fix our attention for a while upon the space that the conductor encloses, and recognize the fact which the little delicate needle demonstrates to us, that something is going on in that space, something quite as important, perhaps more important, than that which takes place in the conductor.

Whatever the magnetic forces are, we know they cannot be called into existence instantaneously. Time must always elapse before the full effect of an electric current is felt, and the greater the forces developed the longer are they in reaching the maximum. Moreover, the current in the wire cannot be at once developed; it keeps pace with the magnetic force and reaches a maximum only when the magnetic forces reach a maximum. This is exactly what would follow if magnetic forces result from the setting in motion of wheels possessing inertia. Whatever magnetic forces may be, they begin and end like the motions of massive bodies.

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Continuing our hypothesis, an electromotive force would be anything that tends to set the wheels in motion. The wheels are set in motion if a limited number acted upon by the E. M. F. are separated by a conductor from the other wheels of space; but, even if they are not separated, that is, if the conductor does not form a closed circuit, the wheels are rotated through a small angle depending on the elasticity of the wheelwork. This displacement constitutes an electric charge, the tendency of the wheelwork to spring back is *difference of potential*, and this difference of potential is maintained by the E. M. F. Here allow me to call attention to the distinction between difference of potential and E. M. F. I often see statements that indicate that the distinction is not clearly kept in view. In that excellent little volume, the Dictionary of Electrical Terms, the statement occurs that electromotive force is *due to* difference of potential. It should

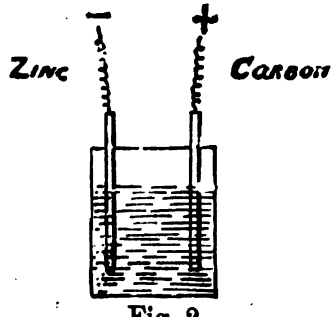

Fig. 2.

rather be difference of potential is due to E. M. F. Difference of potential is *an* electromotive force, but not all electromotive forces are difference of potential; and, furthermore, I can think of no case of difference of potential that does not owe its existence to some other electromotive force, not difference of potential. Difference of potential is a moving force acting from within. Electromotive force acts from without. Difference of potential results from a changed electrical distribution, an electric strain, and represents the tendency to return to the state of equilibrium. Electromotive force is the something from without that produced the electric strain. Consider our wheelwork illustration. I may seize a wheel here and turn it, but I can only turn it through a small angle before the elastic forces, brought into play by the distortion, balance the force that I am able to exert. My force is electromotive force, the elastic forces are difference

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of potential. Let Fig. 2 represent a voltaic cell with its copper and zinc plates and dilute acid; we know that something takes place by which the copper becomes positive and the zinc negative, and, if the copper and zinc be joined by a wire, electricity is said to flow from the copper to the zinc through the wire, and from zinc to copper through the liquid. The flow through the liquid used to be explained by assuming the zinc to be positive and the copper negative within the liquid; just the reverse of what we find without. But connect the copper to the zinc by a wire under the liquid, the current flows through the wire from the copper to the zinc. The copper, therefore, is not negative, but everywhere positive. Then why does the current set from the zinc to the copper through the liquid? Because there is an electromotive force, not difference of potential, mind you, for the difference of potential tends to cause a flow the other way, but a something that forces the current through the liquid against the electric pressure. The cell is an electric pump that pumps electricity from the zinc into the copper until the pressure becomes so great that the pump stops. Open a passage from the copper to the zinc by connecting the two by means of a metallic wire, the electricity flows and relieves the pressure, the pump begins to work and so maintains a continuous flow. No; E. M. F. is not difference of potential. although difference of potential is E. M. F. It is even possible to produce an electric current without any difference of potential whatever in any part of the circuit, just as it is possible to produce a flow of fluid without any difference of pressure.

Whatever difference of potential may be, it behaves like a force developed by an elastic displacement in a solid body. Whatever magnetic forces may be, they behave as though produced by the motions of inert masses. An electromotive force, suddenly brought to bear at a given point, has to overcome not only the elastic force but the magnetic inertia. In other words, an electromotive force, tending to produce current, immediately develops a difference of potential against which it must act, and also develops magnetic forces which retard its action; so a *fluid-moving force* meets opposition in the elastic force of the fluid and in the inertia of its particles. But the effect of any such force is propagated through the medium with a finite velocity expressed by the well-known formula.

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$$V = \sqrt{\frac{E'}{D.}}$$

Electric displacements ought, therefore, to be propagated with a finite velocity which should have some relation to the ratio between the electrostatic effects, analogous to elastic displacements, and the electro-magnetic effects analogous to the effects of moving masses. You all know that it is shown that this velocity is expressed by the ratio of the magnitudes of the electro-magnetic and electrostatic units quantity, and you know also that determinations of this ratio show it to be the velocity of light. This determination gave a very strong support to Maxwell's electro-magnetic theory of light, and, coupled with the fact that observations, so far as they went, indicated that magnetic effects are propagated from the sun to the earth with the same velocity as light, made the theory at least extremely plausible. But within two years the wonderful experiments of Hertz have demonstrated beyond question that electro-magnetic waves travel through space from every source of alternating currents or potentials, and that the waves travel with the velocity of light. In this city there are, I suppose, many alternating current systems. When we think of these in action we are apt to think only of the activity in the conductors of the machines, the lines, the transformers, the lamps, and yet we know that in all the space around there is activity. Waves are chasing each other through this room, through our streets, our houses, our offices. They are everywhere present. We are bathed in this agitated medium every moment, and yet we live, and not only live, but are totally unconscious of the activity that surrounds us. No sense responds to the wave motion that fills this space. And yet, when these waves become short enough and frequent enough, they do affect our sense of vision and a vast array of phenomena that otherwise would have had no existence for us, are made known to us through this special sense. But the eye only responds to waves of $\frac{1}{70000}$ to $\frac{1}{37000}$ of an inch in length, while the length of the waves emitted by one of our alternating current systems is 600 miles. The waves that affect the eye must occur at the inconceivable rate of at least 400 millions of millions per second, while less than 300 waves per second are emitted from our alternating systems. These waves come very far short of the number necessary to affect any of our senses; but we have been able to demonstrate their existence, at least we have been able to show

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that something possessing all the characteristics of wave motion exists in the space around a source of alternating currents or potentials. It is something to know that waves of such enormously different lengths and frequencies exist in the medium that is agitated by waves of light. It is something to understand that our sources of alternating currents are centres of radiant energy, differing from light only in wave length; and since we have begun to appreciate this fact, we have often asked ourselves the question: Can the rate of alternation be increased until the whole apparatus should glow with light? Although the enormous rapidity required seems to render this direct solution impossible, it seems to me there must be a way to obtain the light we want without all this waste of energy. I cannot believe it will always be necessary to develop waves of all lengths from many miles down to a hundred thousandth of an inch, in order to obtain the narrow range of wave lengths by which we see. I do not know of any practical way of obtaining the few wave lengths that constitute light without at the same time producing the others, but it *is* done. The glow-worms do it, the fire-flies do it, the lantern beetles do it, and I believe the time is coming when man can do it. Instead of getting 10 16-candle lamps per horse-power we ought to get 200. I don't know how it is to be done. I don't expect we are going to make alternating machines to produce 500 millions of millions of alternations per second. But possibly we may solve the problem indirectly by the use of some substance having a special rate of vibration, such as the gases. Possibly we may be able to exite electrically the fluorescent salts. Possibly we may be able to charge and discharge a condenser and take advantage of the oscillatory discharge to set up vibrations of the frequency required. Possibly we may discover the secret of the glow-worm and fire-fly and substitute electric for the insect energy. I know it will take several fire-flies to equal a 16-candle lamp, but it will also take a good many fire-flies to develop a horse-power. But although I do not see at present any practical solution of the problem, I repeat, I believe the problem can and will be solved. We are not going on forever burning a coal mine whenever we want a little light. Neither are we going on forever converting the energy of coal into heat when it is mechanical or electrical energy we want. From the very nature of things not more than one-fourth or one-third the heat so produced can be transformed into any other form of energy. The energy of

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fuel *can* be converted into mechanical energy without first becoming heat. It is so converted in every animal movement. The way exists; let us find it. Find this, and the way to make light only, when it is only light we want, and we shall have lengthened the life of our coal deposits five or ten times. The man who solves either one of these problems will be the greatest discoverer of this or any other age. If he gets a broad patent on it, he will have seventeen years of the grandest litigation the world ever saw.

Now I can imagine that some electrician will consider that the first part of this paper dealt with matters that are of no practical consequence in the use of electric currents. Of what practical consequence is it whether force is conveyed to a distance by means of a medium or simply acts at a distance. What does it matter whether electric energy is conveyed by the conductor or through the dielectric? We know how to proportion and dispose our conductors to produce a given effect, and that is enough. But consider what we have learned already of the intimate connection between light and electricity, and I think you will agree that the more we know of the ultimate nature of electricity the nearer we shall be to the solution of the great problem to which I have referred, and the solution of either one of those problems would revolutionize some of the most important industries of the world. May not the solution of at least one of these problems be accomplished and the results exhibited at the great exhibition to be held in 1892? What a wonderful achievement it would be to light all those great buildings without heat, or drive all that vast array of machinery without a fire!

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DISCUSSION.

THE CHAIRMAN, (George M. Phelps):—Professor Anthony has very pleasanty led us into a realm of speculation—not altogether speculation, because it is founded on many things known before, and I am quite sure that some of you will be glad to follow him immediately in treating of the topic that he has so happily opened.

DR. OTTO A. MOSES:—I have to thank Professor Anthony for a most interesting lecture. It has indeed set our thoughts moving. I presume that all of us here have been very deeply interested in those speculations, because though they may be speculations, they are the scaffolding upon which the whole science of electricity has been based. It was the pursuit of a hypothesis that led

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Kepler year after year through very patient investigations to the results which revolutionized astronomy. The same course led Faraday, step by step, to those determinations which finally culminated in what we are now first recognizing—the identity of electricity and light. So that I can say that we have all been gradually accustoming ourselves to these speculations, even though many of us may be engaged in the practical uses of electricity.

There are some remarks in Professor Anthony's very interesting observations to which I would like to call particular attention, more especially the last, as bearing upon our practical applications of these speculations. He spoke of the possibility of using the molecular action of gases as a means of transforming wave-lengths. If my memory serves, that has been done ever since the Ruhmkorff coil has been in operation and the Geissler tube has become so perfect an analyzer of the electric current. In that respect we have already anticipated some of these results. Let us consider what we already have. In the Geissler tube you have the attenuated gases; you have two disconnected poles; you have a current passing, and the wave-lengths broken up and the light produced. So that we have right there before us the facts. Whether we can ever utilize the Geissler tube to effect these immense economies that the Professor so pleasantly prophesied is a question to be determined. It has been experimented upon, and I have found in my short experience in life that these things come when they are needed. There are certain groups of ideas that must be exhausted before people will adopt others and investigate them. We have seen it in the development of all the different branches of electric appliances. We have seen it in the telegraph. We have seen, for instance, Morse using Wheatstone's method of transmission; we have seen him abandon it. We saw him commence with underground conductors; we saw him abandon them simply because the art of that day was not perfect enough to allow him to supply them with profit; so that we can unearth many and many a theory now which already existed, but only awaited the development of the arts to be put into practice.

Now there is one thing I would like to add as a brief supplement to Professor Anthony's predictions. It is in no critical spirit that I mention it, because I will be running somewhat counter to the mechanical hypothesis upon which he developed many of his remarks. One, with great humility, must undertake to oppose himself to a theory emanating from such a mind as that of Clerk Maxwell, but one of the difficulties in the minds of all great mathematicians is that they must put their thoughts into mechanical methods in order to be able to weigh and measure directly. If we could only divest ourselves of the fact that they considered all nature to be composed of molecules, we would then come into another range of thought. I see myself no necessity for imagining all nature split up into infinite particles—

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infinite in number and infinitely small and large in size. I can readily conceive of a continuity of matter. In fact, that thought is no novelty. It has been woven through all science, only we are so accustomed to limitations in our contact with nature, that we are apt to conceive that those limitations actually exist beyond our mere perception of them. As Professor Anthony said, very properly, there is an immense difference in our sense of observation between a wave length of electricity and one of light, but there is no reason that there is not a perfectly insensible graduation from the wave of electricity into that of light. In fact we see it when the current changes from heating effect into light.

A MEMBER:—There is one point I would like to have explained in the wheel hypothesis: To increase the current of a conductor without increasing the heat waste, it is necessary to increase the area of the conductor. I should think that would increase the number of wheels inclosed in a conductor, and therefore increase the friction and the amount of slip, and thus increase the heat developed instead of decreasing it.

PROFESSOR ANTHONY:—As I understand it, the more wheels there are in a conductor, the less is the amount of energy spent in causing the slip over them, because you have got more surface for slip. What we call a given current is accompanied by certain magnetic effects That would mean that the wheels in space enclosed by the conductor are revolving at a certain rate. Now supposing those all to be revolving at the same rate and increasing the size of the conductor and increasing the number of wheels there are in it, the wheels that are in the conductor will be set revolving at a less rate instead of a greater one, because there will be greater surfaces where the slip can occur.

PROFESSOR M. M. GARVER:—It is rather curious to me that generally speaking all the heat developed in the conductor, as Mr. Heaviside looks at it is an action around the conductor. In that connection I cannot see, if it takes place around the conductor, why the law of temperature should hold as it does in the case of metals. Take for instance, the case of copper; I believe the variation is about two tenths of one per cent. for one degree Fahrenheit. If the same law holds, for 500 deg. below zero Fahrenheit there should be no resistance and no heat developed in the conductor. I believe some experiments have been made in regard to the conductivity of copper at very low temperatures. I would be glad to hear from any one who has knowledge of this subject.

MR. A. E. KENNELLY:—I think it would be unnecessary for me to add my own personal views to what I am sure is the universal sentiment concerning the paper to which we have had the pleasure of listening. But while it is full of food for reflection from both a theoretical and practical point of view, I hope there is one point more that may be permitted to be brought forward, that is, the great difference between what might be called a working theory and an ultimate theory. Tracing back the history of any of the

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sciences, as they are so called to-day, we see how very wide-spread they were, how numerous the sciences were, how in the Greek days every activity such as the motion of a cloud and the motion of a body in the air, was supposed to proceed from some superior cause, and gradually as knowledge increased and as investigation pursued its quiet path, those forces were singled out and found to be fewer and fewer, and so to-day, we stand with a certain number which we still hope will be reduced and finally embodied in one. Dr. Moses has given us a very beautiful, I might almost say, a poetic view of what he calls the infinitude of nature, but I think it would be a finer expression perhaps, if he will allow me the correction, if that infinitude be considered as proceeding rather from the unity of nature. In fact if we go back to the days of Polytheism, the old Mahometan cry "There is one God" stands very aptly by comparison. In the theory of heat for example there were what we call now the crudest notions prevalent about four hundred years ago as to what its nature might be. Slowly those views have become clearer, and now perhaps heat is in its theory more complete than any of our other sciences. But the trouble with heat has been the same as it is now with electricity—the difficulty of getting first a theory that was workable and then a theory which would account for the facts clearly and consistently. We have listened to the explanation of a beautiful theory, a theory worthy certainly of the master minds that originated it; but, somehow it does not appear as though that theory were going to be the ultimate one which would satisfy us when we come to consider nature as a whole, and that although it is a good working hypothesis—a peg upon which we can hang our thoughts—that after all we may hope for some simpler and more universal distribution of matter than spinning wheels in space. A vacuum was once supposed to be the absence of everything from space, and nature, as we read in the old books abhorred a vacuum but gradually people began to find out there must be something left, because phenomena take place which could not be accounted for if there were nothing there, for we cannot conceive of action through nothing, and gradually as light came to be considered no longer on a corpuscular theory, it became necessary to invent a new ether and finally the question arose, will not the same ether do for both? Then came the electro-magnetic theory of light and that required a special ether, but that also has been united. Now for the brilliant work of Hertz and Maxwell we see that those two ethers are one and the same; at least we cannot distinguish between their properties. The ether that we suppose will propagate light, is surely not one that we can readily unite with the idea of spinning wheels in space. The mere fact that the thing is difficult to conceive of, is no bar of course to its truth. But we are entitled to the expectation that nature in her infinity is infinitely simple. Surely, it is in this ether that we have to in-

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vestigate something which unites more readily the functions of gravitation of light and of electricity. If we have, for example, a vessel full of incompressible fluid—water will answer—and we introduce two little jets, small by reference to the whole vessel, and we cause the vessel to be hermetically sealed, full of water, then if we force water out of one jet, back through the other, causing a circulation to take place, we shall find, if there be no vortex-motion in the liquid, and if all the particles advance in ranks, shoulder to shoulder—that the lines pursued by the individual particles are, strangely enough, the lines which are followed, we have every reason to believe, by magnetism, by heat and by gravitation. Surely there is some grand principle under lying that great class of phenomena which some day in the future will join them all into one coherent principle.

The point that Prof. Garver mentioned about the conductivity of copper at a very low temperature certainly has great practical interest although we are not likely to live in a climate where for the sake of our conductors we submit to two or three hundred degrees below zero. But I think that experiments have been made at minus 40 degrees centigrade which showed a very large increase in the conductivity of copper, and the co-efficient of temperature was very much larger at that point than it was higher up the scale. The late Sir William Siemens had a very interesting theory that the resistance at a very low temperature was very small indeed, but rose rapidly at first and slower and slower afterward. That is contrary to our orthodox views about conductivity of copper at high temperatures, but it is a view which is interesting in itself.

MR. TOWNSEND WOLCOTT:—Regarding the existence of a medium, Professor Anthony has given voice to the most general opinion in saying that action at a distance is unthinkable. I believe this is the view which Sir Isaac Newton took; but it must not be forgotten on the other hand that Roger Cotes said that there is no *a priori* reason for disbelieving in action at a distance any more than any other experimental facts that we have, and it is this same Roger Cotes of whom Sir Isaac Newton said in speaking of his untimely death: "Had he lived we should have known something." I think that a part of the difference between these two classes of thinkers arises from their having a different conception of the meaning of the word medium. In the present state of the science, if we do not make the word medium mean too much, it is in my opinion practically demonstrated that there is a medium. If we say that action at a distance through space—vacant space—is unthinkable, what do we mean by space? If we mean simply extension, the concept of extension being simply three dimensions, it is unthinkable. But in conceiving of a medium we are too apt to make the word mean too much. Now, Professor Stokes has shown that the luminiferous ether acts like an elastic solid; that is to say the mathematics of solid elasticity

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apply to the ether; but in order that it should be an elastic solid which had the same degree of elasticity as the ether does have, on that hypothesis it would have to be an exceedingly solid kind of a solid. I forget how much pressure there would have to be, but it was something enormous. Now, we know that the ether is not such a solid as that. Again taking the modern theory that the action of the dielectric is a stress, we may apply the same comment to this also. The mathematics of stress are equations similar to the equations that apply to electric phenomena in a dielectric. However, there can be no real stress in the sense in which we understand the word, because the very bodies which can not sustain a stress are the ones which are the best dielectrics. In fact a vacuum, which we do not consider a body at all, is a dielectric, and, according to some electricians, it is the very best of insulators; and metals which generally are capable of sustaining a great deal of stress, are all conductors and, according to theory, are bodies in which the state of dielectric stress cannot exist, but gives way immediately, producing what we know as current.

Dr. Michael Pupin:—I would like to express my feeling of obligation to Prof. Anthony for his able lecture on the modern theories, and with his kind permission to add a few comments as a supplement to his review. We know what ideas Faraday had of dielectrics and the function which they perform in the transmission of the electric action from one part of space to another. We know that Faraday supposed the dielectric to be filled with small conducting particles which have the property of polarity. In what that polarity may consist we do not know. We may suppose it is of the same kind as the magnetic polarity in the case of soft iron. That theory has been worked out by Professor Helmholz, and he deduced the equations for the distribution of the stress in the medium of the dielectric exactly the same as Maxwell did. In fact the equations which Helmholz obtained are a little bit fuller. Now, given that a dielectric consists of very small particles, each one having the properties of polarity and all the electro-static and all the electro-magnetic phenomena can be explained. I do not see that it is necessary to go into the consideration of wheels working within other wheels. To be sure Maxwell did work out the theory in 1862, I think, to which reference was made this evening, but he gave it up, and in his second volume on electricity he refers to this theory in a sort of off-hand way, saying that some years ago he worked out a theory of electricity based on the hypothesis of Sir William Thomson of vortex motion. Helmholz, supposing the medium to have only this property of polarization—these papers are not published yet, but I expect they will be published very soon, though they are not very new, because these things have been worked out before by Sir William Thomson, and I think by Maxwell—shows that if there is any electric disturbance, whether it be an electro-static or electro-magnetic, in the conductor must be propagated

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in the whole dielectric, because disturbance in the electric state of the conductor will cause a disturbance of the stress in the dielectric, and that disturbance of the metal gives the electromagnetic action.

Every one of the speakers this evening has spoken of forces. The term force is very elastic and may mean almost anything. In fact, I think every man has his own idea about force. But if we are to discuss and use the term we must have the same definition. I think if we are to treat sciences from the mechanical standpoint, then we must define force mechanically. That is, we must fall back necessarily on the Newtonian definition of force, *i. e.* as producing nothing but motion—this is the elementary definition of force. When we speak of electric and magnetic forces we certainly deal with something which will produce more than motion alone. Take, for example, Ampere's integral law, by which we know that a current flowing through a conductor will act upon a magnetic pole just the same as if the wire was an empty shell having a magnetic moment equal to the strength of the current. But, in every department of science it is always desirable, and in fact it is the highest aim of every physicist to deduce, not the integral law but the differential law. Newton achieved his great success when he found the differential law—the law of universal gravitation. Ampere thought his integral law would be of little use to him if he did not know the differential law, namely, the law which determines the action of each element of one conductor upon each element of any other conductor or upon itself. He said, let us now resolve this integral action into elementary actions. He did it and he found that each element of the conductor acts upon a pole or upon an element of another conductor with a force which is not exerted in the line connecting the two, but perpendicularly to that line. Other differential laws have been deduced in the last twenty years by Maxwell, Weber and Helmholtz. Some of these laws suppose that there is not only a force perpendicular to the line between the two elements, but also that there is something that tends to turn the element, so that we have to deal here not only with forces, which are determined by laws of mechanics, but with forces that lie entirely outside of that. Therefore we are always to carefully distinguish what we mean by force. Is it purely mechanical force, or is it a force which produces, besides motion, something else? We cannot speak of chemical forces in the same way as we speak of mechanical forces, because mechanical forces are limited by the definition of Newton and they produce nothing but the motion of the mass. Chemical force produces heat; it produces chemical composition and decomposition; it produces light and it may produce motion also. We do not deal here with pure forces such as gravitating force which is always exerted in the line connecting the two points acting upon one another.

The other point which I would like to mention refers to con-

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ductivity. A gentleman said that the rule—I will not call it a law—is that every metal increases its resistance with temperature, and therefore at a certain low temperature it ought not to offer any resistance at all. The fallacy is self-evident. When we speak of a law we do not mean something absolutely true. Clifford has defined its meaning; a law is true only for those conditions under which the particular phenomena which led to the construction of the law were observed. The law of heat, the law of light, the law of electric current were observed; not in a temperature of several million degrees, but in temperatures which we can get ranging from minus 80 degrees centigrade to perhaps 3000 degrees centigrade, the highest temperature which we could obtain. Therefore the law above those limits may be true or may not be true. Every law may be represented by a certain curve. Where the curve does not run from minus infinity to plus infinity we know a very small space of that curve; the rest we do not know.

PROF. GARVER:—I see I was misunderstood in reference to the conductor. I was speaking of the fact that at first sight it seems that the variation in conductivity due to the temperature in the conductor was at variance with the view that the action took place outside instead of inside the conductor. Since thinking it over I have arrived at what seems to be a plausible answer to my own question, that the conductor, being actuated by heat, the particles are in motion. Now, as the temperature of the conductor goes down, the heat action becomes less and less, and it then approximates to what I believe it is supposed to be—a hole through the medium.

MR. NIKOLA TESLA:—I want to suggest a practical idea on which I have not taken a patent, but which is cheerfully offered in case any gentleman wants to patent it. There seems to be no doubt to-day that light and electricity are one and the same, and that between the two there is only a difference in degree. Now, the question resolves itself into how to produce a sufficient number of undulations to equal those of light. We know that if you put two coils in inductive relation and pass through the primary an undulating current you can produce in the secondary two distinct currents. Then from that secondary we can again act in the same manner upon another coil and so on I have figured that at that rate it would require about 23 conversions. If you assume an efficiency of 80 per cent in the first you can assume one of 2 per cent. in the last coil which is the twenty-third.

Now there is another thing I wish to mention. That is, that while we are convinced that light and electricity and electromagnetic action are the same, yet there seems to be a difference between light and electricity in that we cannot maintain light in a static state; but we can maintain electricity so. And again light and magnetism are similar in this respect That when we attempt to store, for instance, magnetism and light—a problem

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which is very interesting and would be very valuable if solved—we know well that we can magnetize steel and it will hold magnetism indefinitely. We can also magnetize a soft iron bar but it will lose the magnetism soon. Now there seems to be, from what Prof. Anthony has so admirably set forth, a possibility of producing a magnet of such qualities that it would for an indefinite time, say for a year or more, continuously discharge its magnetism after a cessation of the current which energized it. Then we could store electricity. I attempted in my early days to do that, but it does not work. Another thing in regard to light—if we expose certain bodies to an arc light or a very intense source of light we will find that they will take up light for the first moments, but when the light is intercepted it will instantly fall and the little that remains will gradually disappear, and sometimes it will take considerable time, similar to that little remnant of magnetism in the big bar of iron. If we plot the curves in the two cases we would find them similar, which shows that magnetism and light correspond in this way. Whereas we know that electricity can be stored—I understand now the difference which Prof. Anthony has brought out between potential and electro motive force—I mean we can take the condenser or a Leyden jar and store up electricity in any quantity, so to speak, and keep it there for a considerable time, and then discharge it at will. We cannot do so with light nor with magnetism, and yet we know that all these are really one and the same thing with only a difference of degree.

DR. PUPIN:—I would like to ask Prof. Anthony to define the term electromotive force.

PROF. ANTHONY:—It is one of the most difficult things in the world to give the definition, and I never pretended to any ability at giving definitions. We all know that in a battery there is something that develops an activity. We know that the conductor gets warm. We know that around the conductor there are what we call magnetic forces, and I believe that there is an activity set up in the whole space around it. Now, whatever there is inside of the battery that gets up this agitation I call electromotive force. Furthermore, we know that if we take a wire and move it across the magnetic lines of force there exists something which, if that wire formed a closed circuit, will produce what we call a flow of electricity. We know it is full of electricity, because, under proper conditions the wire will get warm, because also, there are magnetic effects developed by it. There is something takes place—an agitation is set up in that wire, and I consider that something, I do not pretend to define it or to know what it is, but there is something there in consequence of the movement of that wire across these magnetic lines of force that constitutes what we call electromotive force. It is something, to use the language of electrical theory, that puts electricity in motion, and that is the action I referred to in the paper in which

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we may have electricity in motion in a conductor without any difference of potential. Suppose, for instance, I have a perfect circle formed of wire, and then I take a magnet, and suppose I thrust the north pole of the magnet perpendicularly into the very centre of that circle. We know that lines of force cut that circle all around in every part, and when that magnet is thrust through there we know that whatever there is that constitutes a magnetic field acts in some way to set up this current and acts in every part of the wire so that there is a current set up without there being any difference of potential in any place.

DR PUPIN:—How would you measure the heat produced in wire? Is that subject to Joule's law?

PROF. ANTHONY:—I should say so, certainly.

DR PUPIN:—It is equal to the electromotive force multiplied by the current. What is the electromotive force? It is that which we define mechanically in absolute measures.

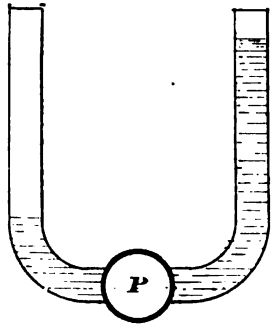


Fig. 3.

PROF. ANTHONY:—It is whatever sets that current in motion around there.

DR. PUPIN:—Yes, but we know it, we can define it in terms of time, mass and length. It is perfectly definable.

PROF. ANTHONY:—It is measured in the same terms as difference of potential, of course.

DR. PUPIN:—It must be the same.

PROF. ANTHONY:—I do not think so any more than in difference of level. We measure difference of pressure, for instance, by difference of level in the case of water. To illustrate it—here I have a U tube with a pump in it. The water is at the same level in both branches. I now set the pump turning and the water falls in this side and goes up in the other. That difference of level will measure the difference of pressure, but that pressure was produced by turning the handle on this pump. Now the turning of the handle I call the water-moving force. This constitutes a difference of potential, a difference of gravity potential which opposes my turning of the handle. (See Fig. 3.)

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DR. PUPIN:—Therefore the work done measures the difference of level.

PROF. ANTHONY:—It may be measured by the difference of level.

DR. PUPIN:—But the work done measures the difference. The electromotive force is not a force at all in the usual sense of the word. It is the work done to make the difference of potential and that is what the difference of potential is—the work done.

PROF. ANTHONY:—Suppose that we do not produce any difference of potential, as in the case of the circle of wire with the magnet thrust into it.

DR. PUPIN:—But we do. That is a well-known problem.

PROF. ANTHONY:—The difference of potential is equal to the work done. I may just as well say substitute for each element in that wire an infinitely small Daniell element all around. Of course that is practically impossible, but let us suppose so. We can place infinitely small Daniell elements, connecting them together around the circle so that they will form a closed circuit, where is the difference of potential there? If you have them infinitely small so that each Daniell element acts on each element of the wire then I should say there was no difference of potential from one end to the other, and we have the electromotive force of the Daniell element producing the result entirely and nothing else.

DR. PUPIN:—There is a difference of potential between each two poles in every one of those infinitely small cells. So I may say between the ends of each one of the infinitely small elements of the wire there is a difference of potential and these being connected in series the current runs around them.

PROF. ANTHONY:—Let us take it in another way. Suppose there is a circular tube containing a gas or liquid, whichever you please. Now, can we not conceive of such a thing as something acting simultaneously upon every single element, no matter how many you consider there may be of them, so that every one of those elements will move forward at the same instant, and that there is no difference of pressure anywhere in that case. Now, difference of pressure is what I consider as equivalent to difference of potential. In other words what we call difference of potential electrically is due to a disturbed electrical distribution and until you have a disturbed electrical distribution there is no difference of potential. Now, in this wire where we have a perfect circle and thrust into it the magnetic pole, we act on every element of that wire simultaneously, there is no disturbed condition of potential, and after you have stopped the magnetic pole you can conceive that your electricity has been shifted around through the whole of it without there being a disturbance there—without any difference of potential. You stop the movement of the magnet—the current stops. Your electricity does not fly back again. But let us cut that wire in two and leave an opening in it. Now

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force the magnetic pole through the middle and you tend to make a motion around it in the same way. Electricity is heaped up at one end, making pressure there, and the moment your magnet stops the electricity flies back and produces a current the other way.

MR. FRANCIS B. CROCKER:—It seems to me that Prof. Anthony's last illustration will give us a solution of the problem and reconcile both sides of this controversy. He assumes that the wire circle is opened at a certain point, and if you thrust in a magnet you get at that point the total difference of potential which we could calculate and predict from known electric and magnetic effects Now it seems to me that when the circle is closed, you get that difference of potential spread over the entire con ductor which produces the current through that resistance. It is heaped up at the point of opening because it cannot pass that point, there being no conductor there. But it appears to me that, if we close the circle at that point and make it uniform as regards resistance, the potential is distributed uniformly around the entire circle. But even when distributed in that way it produces the same effect as it would if it were concentrated, and it would seem that although there is no difference of potential which can be detected yet the same total difference of potential really exists throughout the circle. In other words the integral of the difference of potential is the same in both cases, because the current in the circuit and the Joule effect and all those other electrical phenomena will be precisely those due to the difference of potential which we get when we open the circuit. Theoretically the way to treat such a case is to differentiate—take a certain element and treat it by itself. Taking a certain element there, we have a certain difference of potential, a certain resistance and a certain resulting current. Take for instance that circle and assume it for the purpose of the hypothesis to be divided into a thousand equal portions. Then we have one 1000th of the total difference of potential and one 1000th of the resistance in each element, and therefore we have the same current as with a thousand times the electromotive force and a thousand times the resistance. This seems to me to be merely a particular case—an electrical paradox.

MR. WOLCOTT:—Mr. Crocker's idea of the circulation of current there is a good deal like the relation of east and west on the globe. We can have a point west of New York and by going in the other direction it will be east of New York. If we take Mr. Crocker's view and integrate the difference of potential all around the ring, when we get back to the starting point, that point has two potentials, and so it must be It is like any other cyclic region. One of the most familiar cases of that is the magnetic potential. In an infinitely straight conductor the potential at any point has an infinite number of values, but it is only on some such conception as that, that you can consider there is any difference of potential. Each point has a potential different from itself.

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That is by going around until you come back to the same point you have increased the potential, by the cyclic constants of the curve.

MR. KENNELLY:—I think we are very much indebted to Prof. Anthony for having called attention to one of the leading misconceptions of the day. There is a constant conflict between difference of potential and electromotive force, and I think nothing can be better in a society of this kind than to settle such confusions. I think Prof Anthony has given us a very clear solution in this way, that whatever produces a current is electromotive force; that electromotive force may or may not be accompanied by a difference of potential. We do not recognize potential as we recognize current. We are led to it by a series of abstractions. Potential was introduced on a purely theoretical and mathematical basis. The potential function first existed in gravitation. It was introduced into electricity by similarities which exist between gravitation laws and electrical laws in their mathematical form, and the potential is something which causes work to be done, in virtue of which work can be done. The potential is measured by the work done in bringing a unit of electricity to the point whose potential is to be determined.

DR. PUPIN:—I do not agree with the last speaker, that potential is a mathematical conception any more than I would agree with him that work is a mathematical conception. Who would say that to raise a barrel of flour to the gallery above us here is a mathematical conception? To charge a conductor with a certain amount of electricity, we must do a certain amount of work. If we do not stick to this term work, we cannot make a step of progress, because we cannot use the principle of the conservation of energy. Potential is not a mathematical conception. Potential is as concrete as the fact that I am standing here. It is the amount of work done. He said that difference of potential is something which causes work to be done, and a little while before that, he said that electromotive force is the cause of the electric current. Now these two things seem to me to be one and the same, because work must be done to cause the current to flow; but I will not discuss the subject any more, seeing that my colleague has expounded my idea of this circular conductor in a very nice and masterly way.

THE CHAIRMAN:—We certainly have had one of the most interesting evenings in the history of the Institute. I think the discussion has been very suggestive in many ways.

On the 18th of February, will occur the next meeting of the Institute, when a paper will be read by Mr. William Maver, Jr. and the topic will be, "The Practical Working of New York's Electrical Sub-ways." You may expect that to be an extremely interesting paper, full of surprises.

Adjourned.

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OF

# CURRENT ELECTRICAL LITERATURE,

&c. (August, 1889.)

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**Telegraphy in the Holy Land.** *Elec. World*, Aug. 24, p. 124.

**Telegraphy Regarded from a Financial Point of View.** (High Speed and Low Speed) P. G. H. Linckens. *Lond. Elec. Rev.*, Aug. 16, p. 172.

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**The French Chamber of Deputies and the Telephones.** *N. Y. Elec. Rev.*, Aug. 24, p. 7.

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## ELECTRIC LIGHT.

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**The Rulings at the National Electric Light Convention.** (Corr.) E. R. Weeks. *Elec. World*, Aug. 24, p. 133; *West. Elecn.*, Aug. 24, p. 107; *N. Y. Elec. Rev.*, Aug. 24, p. 5.

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**A Recent Search Light Experiment.** *Sci. Am.*, Aug. 17, p. 96.

**A New Incandescent System.** (Ill., *N. Y. Elec. Rev.*, Aug. 31, p. 9. (Loomis.)

**Power Plant in the Yonkers, N. Y., Electric Light Station.** (Ill.) *Elec. World*, Aug. 10, p. 91.

**Electric Lighting in New York.** (Ill.) *Elec. World*, Aug, 10, p. 87. (Brush and Manhattan Companies' Stations.)

**The Boston Edison Stations.** (Ill.) *Elec. World*, Aug. 10, p. 83.

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**A Sign Made with Edison Lamps.** (Ill.) *Elec. World*, Aug. 24, p. 131. *N. Y. Elec. Rev.*, Aug. 17, p. 8.

**Lighting the Entrance to the "Times" Building.** (Ill.) *Elec. World*, Aug. 10. p. 82.

**The Decorative Features of the Electric Light on Board the Puritan.** (Ill.) *Elec. World*, Aug. 3. p, 65.

**The Brush Station at Rochester, N. Y.** (Ill.) *Elec. World*, Aug. 10, p. 89

**Heisler Electric Light Company.** *West. Elecn.*, Aug. 3, p. 61.

**The Electric Lighting Bills before the House of Lords.** *Lond. Elecn.*, Aug. 2, p. 331; Aug. 9, p. 346; Aug. 16, p. 384.

**The Electricity Supply Companies Registered during the Six Months ended June 30th, 1889.** (Note) *Lond. Elecn.*, Aug. 2, p. 319.

**The Heisler System at the Paris Exposition.** *Elec. World*, Aug. 24, p. 129

**The Contracts for the Lighting of the City of London.** *Lond. Elecn.*, Aug. 2, p. 322.

**Deptford Central Electric Light Station.** (Ill.) *Indust.; West. Elecn.*, Aug. 3, p. 68.

**Electric Lighting in Australia.** Chas. Flesch. *West. Elecn.*, Aug. 24 p 110.

**Electric Light vs. Gas in England.** *Md. Lt. & Ht.*, Aug. 29, p. 272.

**Electric Lighting Notices for 1889—90.** *Lond. Elecn.*, Aug. 16, p. 377.

**Electric Lighting in London.** (Bill before the Lord's Committee.) *Lond. Elec. Rev.*, Aug. 9, p. 152; Aug. 16, p. 187; Aug 23, p. 217.

**Will Electricity Supplant Gas?** *Lond Elec. Rev.*, Aug. 2, p. 117.

**The Electric Light at the St. Lazare Railway Station, Paris.** *Lond. Elec. Rev*, Aug. 2, p. 119

**Scotch Gas Managers and Electric Lighting.** *Lond. Elec. Rev.*, Aug. 2, p. 125.

**Electric Lighting in Algeria.** *Lond. Elec. Rev.*, Aug. 16, p. 174.

**Electric Lighting vs. Gas.** *Lond. Elec. Rev.*, Aug. 16, p. 174.

**Gas and Electric Lighting in Paris.** *Lond. Elec. Engr.*, Aug. 30, p. 171.

**Windmill for Producing Electric Light at Cape de la Heve.** (Ill.) *Sci. Am. Supp.*, Aug. 3, p. 11,327.

**The Electric Lighting Schemes.** (Commons Select Committee.) (Cont'd from p. 111.) *Lond. Elec. Rev.*, Aug. 2, p. 135; Aug. 9, p. 163; Aug. 16, p. 190.

**On Security Against Disturbance of Ship's Compasses by Electric Lighting Appliances.** *Sci. Am. Supp.*, Aug. 3, p. 11,325.

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## ELECTRIC LAMPS.

**McCreary's Combined Incandescent Shade and Reflector.** (Ill.) *Elec. World*, Aug. 10, p. 82.

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**Goldston's Series Incandescent Lamp.** (Ill.) *Lond Elec. Engr*, Aug. 16, p. 129; *Elec. World*, Aug. 31, p. 150.

**New Sawyer-Man Lamps.** (Ill.) *Elec. World*, Aug. 24, p. 128.

**The Maximum Efficiency of Incandescent Lamps for Central Station Work.** Leigh Carroll. *Elec. World*, Aug. 24, p. 35; *West. Elecn.*, Aug. 24, p. 112.

**The Pieper Semi-Incandescent Lamp.** (Note.) *Lond. Elecn.*, Aug. 2, p. 318.

**Incandescent Lamps.** (Ill.) E. Z. Burns. *N. Y. Elec. Rev.*, Aug 24 p. 1.

**A New Arc Lamp.** *N. Y. Elec. Rev.*, Aug. 31, p. 9. (Planet Elec. Eng. Co., Eng.)

**Arc Lamps and their Mechanism.** (Ill.) S. P. Thompson. (Cont'd from p. 304.) Lond. Soc. Arts. *N. Y. Elec. Engr.*, Aug., p. 344.

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DYNAMOS, TRANSFORMERS.

**The Kapp Alternating Current Dynamo.** (Ill.) *Elec. World*, Aug. 31, p. 150; *N. Y. Elec. Rev.*, Aug. 31, p. 1; *Indust.; Lond. Elecn.*, Aug. 30, p. 425; *Indust.*, Aug. 9, p. 136.

**The Mordey-Victoria Alternator.** (Ill.) *Lond. Elec. Rev.*, Aug. 16, p. 173; *Indust.*, Aug. 16, p. 162; *Elec. World*, Aug. 31, p. 150.

**The "New Century" Dynamo.** (Ill.) *Elec. World*, Aug. 10, p. 86.

**The Dynamo of the Wenstrom Northern Electric Company.** (Ill.) *Elec. World*, Aug. 31, p. 144.

**Rankin Kennedy's Patent on Parallel Converters.** (Note.) *N. Y. Elec. Engr.*, Aug., p. 371.

**The Brush Electric Company's New Alternating Current System.** (Ill.) *N. Y. Elec. Engr.*, Aug. p. 338; *Lond. Elec. Rev.*, Aug 9, p. 150.

**Parallel Introduction of Alternating Current Machines at Marienbad.** (Ill.) *Lond. Elec. Rev.*, Aug. 23, p. 199.

**The Curve of a Westinghouse Machine.** (Corr.) Jas. Swinburne. *Lond. Elec. Rev.*, Aug. 30, p. 252.

**Dynamo Room Accessories of Intensity, Potential and Resistance Measurements.** C. C. Haskins. Nat. Elec. Lt. Assn. *West. Elecn.*, Aug. 17, p. 97; *N. Y. Elec. Rev.*, Aug. 17. p. 14; *Md. Lt. & Ht.*, Aug. 15, p. 174; *Elec. World*, Aug. 17, p. 111.

**A Novel Plan for Driving Dynamos by Water-Power.** L. H. Hallam. *Elec. World*, Aug. 10, p. 83.

**Motor and Generator for Locomotive Headlights.** (Ill.) *West. Elecn.*, Aug. 3, p. 68.

**Heisler Automatic Regulator.** (Ill.) *West. Elecn*, Aug. 24, p. 105.

**A Slide-Rest for Commutators.** (Ill.) Lewis F. Lyne. *Power and Steam; Lond. Elecn.*, Aug. 23, p. 401.

**The Experimental Determination of the Law of Variation of the Electromotive Force in the Armature of a Westinghouse Dynamo.** (Ill.) Lewis Searing and S. V. Hoffmann. Stev. Inst. Tech. *Lond. Elec. Rev.*, Aug. 30, p 233; *Lond. Elec. Engr.*, Aug. 16, p. 126.

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**Methods to Determine the Equivalent Area of Armatures.** Irvin S. Ferry. *Elec. World*, Aug. 31, p. 145.

**Magnetic Leakage in Dynamos.** Prof. H. S. Carhart. *West. Elecn.*, Aug. 31, p. 118.

**The Theory of Alternators.** (Corr.) Llewelyn B. Atkinson. *Lond. Elecn.*, Aug. 23, p. 413.

**Loss in the Armature of Series Machines.** (Ill.) Richard Opitz. *Centralblatt für Elektrotechnik; N. Y. Elec. Engr.*, Aug., p. 353.

**Notes on the Dynamos at the Paris Exhibition.** (Ill) *Lond. Elec. Rev.*, Aug. 2, p. 121; Aug. 9, p. 146; Aug. 23, p. 206; *N. Y. Elec. Rev.*, Aug. 17, p. 1; *Indust.*, Aug. 2, p. 109.

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## SYSTEMS OF DISTRIBUTION.

**The Five-Lead System.** Dr. Krieger. New. Poly. Soc. Königsberg. *Lond. Elec. Rev.*, Aug. 2, p. 118; *Elec. World*, Aug. 31, p. 150.

**Questions on Automatic Regulation, Distribution, Calibration, etc.** (Corr.) *Elec. World*, Aug. 10, p. 93.

**Alternate Current Working.** (Mr. Mordey's Reply.) *Jour.* of Inst. of Elec. Engrs; *Lond. Elecn.*, Aug. 2, p. 326; *Lond. Elec. Rev.*, Aug. 2, p. 133; *N. Y. Elec. Engr.*, Aug., p. 362.

**A Practical Opinion on the Alternate Current System.** (Corr.) B. P. Foster. *Elec. World*, Aug. 10, p. 89.

**Alternate Current Working.** (Ed.) *Lond. Elecn.*, Aug. 2, p. 324.

**Alternate Current Working.** *Elec. World*, Aug. 24, p. 134.

**On the Distribution of Energy by Means of Alternating Currents.** (Ill.) M. Leblanc. *La Lum. Élec.; Lond. Elecn.*, Aug. 2, p. 320; Aug. 9, p. 346; Aug. 16, p. 372; Aug. 23, p. 398.

**Electrical Distributiou by Means of Condensers.** (Corr.) J. D. F. Andrews. *Lond. Elecn*, Aug. 2, p. 330.

**The Edison Three-Wire System of Distribution.** (Ill.) W. J. Jenks. *Elec. World; Lond. Elec. Engr.*, Aug. 2, p. 86; Aug. 16, p. 133.

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## ELECTRIC MOTORS, CONTINUOUS.

**The Perret Motors and Dynamos.** (Ill.) *Elec. World*, Aug. 3, p. 71; *N. Y. Elec. Rev.*, Aug. 3, p. 1; *Md. Lt. & Ht.*, Aug. 1, p. 115; *N. Y. Elec. Engr.*, Aug. 3, p. 356.

**New Crocker-Wheeler Fan Motor.** (Ill.) *Elec. World*, Aug. 10, p. 82.

**The Knapp Fan and Motor.** (Ill.) *Elec. World*, Aug. 10, p. 86.

**Electric Motors for Organ Use.** *N. Y. Elec. Rev.*, Aug. 3, p. 9.

**The Electric Motor in 1838.** *Jour. Fkln. Inst.; Md. Lt. & Ht.*, Aug. 8, p. 147.

**Marcel Depres on the Regulation of the Speed of Electric Motors.** (Ill.) *La Lum. Élec; N. Y. Elec. Engr.*, Aug., p. 342.

**Constant Current vs. Constant Potential Motors.** Emile Kahn. *Sci. Am. Supp.*, Aug. 24, p. 11,372.

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## ELECTRIC MOTORS, ALTERNATING.

**Alternating Motors.** (Corr.) Jas. Swinburne. *Lond. Elecn.*, Aug. 9, p. 359; Aug. 30, p. 436.

**The Westinghouse Motor.** (Ill.) *N. Y. Elec. Rev.*, Aug. 10, p. 10.

**M. Leblanc's Alternate Current Motor.** *Comptes Rendus; Lond. Elecn.*, Aug. 9, p. 357.

## ELECTRIC POWER.

**Coal Mining by Electricity.** *Lond. Elec. Rev.*, Aug. 23, p. 200.

**Electric Motor Power for Western Mines.** *Elec. World*, Aug. 10, p. 82.

**The Latest Form of Sperry Electric Coal Cutter.** (Ill.) *Elec. World*, Aug. 31, p. 148; *West Elecn.*, Aug. 31, p. 123.

**New Brush Apparatus for Power-Purposes.** (Ill.) *Elec. World*, Aug. 24, p. 133.

**Ventilating Fan Outfit.** (Ill.) *West. Elecn.*, Aug. 10, p. 66.

**Electric Motors in Chicago.** *West. Elecn.*, Aug. 10, p. 71.

**Type-Setting Machine Operated by an Electric Motor.** *West. Elecn.*, Aug. 31, p. 119. (*Chicago Ev. Jour.*)

**A Yacht Run by Electricity.** *Md. Lt. & Ht.*, Aug. 29, p. 273.

**Submarine Torpedo Boats.** (Note.) *Lond. Elec. Rev.*, Aug. 16, p. 182.

**Charging Stations on the Thames.** (Note.) *Lond. Elec. Engr.*, Aug. 2, p. 84. (Elec. Launches.)

**Electric Bridges at the Paris Exhibition.** *Lond. Elec. Rev.*, Aug. 16, p. 174; *Sci. Am*, Aug. 24, p. 120.

**An Electric Pump.** (Note.) *Lond. Elec. Rev*, Aug. 30, p 244.

**Electric Power in a Tobacco Factory.** (Ill.) *West. Elecn.*, Aug. 10, p. 71. (Globe Tobacco Co., Detroit, Mich.) *N. Y. Elec. Rev.*, Aug. 10, p. 1; *Md. Lt. & Ht.*, Aug. 8, p. 146; *Elec. World*, Aug. 10, p. 85.

**Problems of Electric Power Transmission. I.** R. H. Smith. *Indust.*, Aug. 23, p. 187.

**Electric Transmission of Water Power at Winterthur.** *Indust.; Lond. Elec. Rev.*, Aug. 9, p. 155.

**Utilizing Niagara Falls.** (Ill.) *Elec. World*, Aug. 10, p. 88.

**Some Applications of Electrical Transmission.** (Ill.) Frank J. Sprague. *Sci. Am. Supp.*, Aug. 3, p. 11,328.

**Electrical Transmission of Power.** Prof. Roberts Nat Elec Lt Assn. *West. Elecn.*, Aug. 17, p. 101; *N. Y. Elec. Rev.*, Aug. 31, p. 6; *Elec. World*, Aug. 17, p 114.

**Wittingham Automatic Switch.** (Ill.) *West. Elecn.*, Aug. 3, p. 55; *Elec. World*, Aug. 3, p. 68. (For motors.)

## ELECTRIC RAILWAYS.

**Excellent Performance of the Sprague Road at Cleveland, O.** *Elec. World*, Aug. 3, p. 68; Aug. 10, p. 92

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**Peckham's Electric Motor Truck.** (Ill.) *Elec. World*, Aug. 24. p 124.

**The Electric Road at Topeka.** *N. Y. Elec. Rev.*, Aug. 10, p. 3.

**The Boston Electric Railway.** *N. Y. Elec. Rev.*, Aug. 10, p. 2.

**A Promising New Company.** *N. Y. Elec. Rev.*, Aug. 17, p 20. (Short Elec. R'y Co.)

**Bentley-Knight Electric Railway Generator and Motor Car.** (Ill.) *West. Elecn.*, Aug. 24, p 106.

**Central Passenger Railroad, Louisville, Ky.** (Ill.) *Md. Lt & Ht.*, Aug. 29, p. 270.

**The Brussels Electric Tramway.** *Lond. Elecn.*, Aug. 16, p. 386. (Corr.) A. Reckenzaun. Aug. 23, p. 413.

**Naini-Tal Electric Railway.** *Lond. Elec. Engr.*, Aug. 16, p. 125.

**Electric Road in a Coal Mine.** *West. Elecn.*, Aug. 31, p. 121. (Hillside )

**The Plymouth and Kingston Street Railway.** (Ill.) *West. Elecn.*, Aug. 10, p. 69; *Elec. World*, Aug. 10, p. 89; *N. Y. Elec. Rev.*, Aug, 10, p. 8; *Md. Lt. & Ht.*, Aug. 8. p. 143.

**Julien Electric Street Railway System.** (Ill.) *West. Elecn.*, Aug. 24, p. 110; *Elec. World*, Aug. 24, pp. 124, 134.

**Electric Railways.** G. W. Mansfield. *Elec. World*, Aug. 17, p. 113. Nat. Elec. Lt. Assn. *Lond. Elecn.*, Aug. 30. p 433; *Lond. Elec. Rev.*, Aug. 30, p. 245; *West. Elecn.*, Aug. 17, p. 99; *N. Y. Elec. Rev.*, Aug. 17, p. 16; *Md. Lt. & Ht.*, Aug. 15, p. 178.

**Electric Traction by Storage Batteries.** Wm. Bracken. Nat Elec. Lt. Assn. *Elec. World* Aug 17, p. 109; *Lond. Elecn.*, Aug. 23. p. 406.

**Some Recent Electrical Work on the Elevated Roads, and its Bearing on the Rapid Transit Problem.** Leo Daft. Am. Inst. Elec. Engrs. *N. Y. Elec. Engr.*, Aug., p. 359; Aug. 2, p. 137; *Lond. Elec. Rev.*, Aug. 9, p. 160

**The Electric Motor Tests on the New York Elevated Railroad.** *Sci. Am. Supp.*, Aug. 17, p. 11,353.

**Electric Traction for Underground Railways.** *Lond. Elec. Engr.*, Aug. 2, p. 85. (M. Holroyd Smith.)

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## INSTRUMENTS, MEASUREMENTS.

**Warner Electric Light Gauge.** (Ill.) *West. Elecn.*, Aug. 3, p. 55; *N. Y. Elec. Rev.*, Aug. 10, p. 7; *Elec. World*, Aug. 10, p. 86.

**The K. M. B. Pocket Galvanometer.** (Ill.) *Lond Elec. Rev.*, Aug. 16, p. 175; *Indust*, Aug. 9, p. 136.

**Reckenzaun Electric Meter.** (Note.) *Lond. Elec. Engr*, Aug. 2, p. 83.

**The John A. Barrett Measuring Instruments.** (Ill.) *Elec. World*, Aug. 24, p. 127.

**The Wirt Standard Voltmeter.** (Ill.) *Elec. World*, Aug. 24, p. 129.

**Electric Micrometer.** (Ill.) *West. Elecn.*, Aug. 3, p. 59.

**Slattery Alternating Current Meter.** (Ill.) *West. Elecn.*, Aug. 31, p. 118.

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**The Measurement of Energy.** M. A. Potier. Paris. Inter. Elec. Con. *Lond. Elecn.*, Aug. 23 p. 405.

**Portable Pocket Ammeters and Voltmeters.** (Ill.) *Lond. Elecn.*, Aug. 30, p. 438.

**Standardising Electric Measuring Apparatus. Announcement of the Berlin Imperial Physico-Technical Office for Testing Electric Measuring Apparatus.** *Lond. Elec. Rev.*, Aug. 9, p. 143.

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ELECTROLYSIS.

**The Preparation of Cellulose by Electrolysis.** *Lond. Elecn.*, Aug. 2, p. 318.

**The Electrolytic Preparation of Iodine.** (Note.) *Lond. Elecn*, Aug. 9, p. 344.

**On the Electrolysis of Distilled Water.** M. E. Duler. *Comptes Rendus; Lond. Elec. Rev.*, Aug. 2, p. 116.

**On the Limit between Polarisation and Electrolysis.** M. H. Pellay. *Sci. Am. Supp.*, Aug. 24, p. 11,372.

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UNDERGROUND WIRES, ETC.

**The Electric Subways of Paris.** (Ill.) *Elec. World*, Aug. 31, p. 147.

**Underground Conduits and Electric Conductors.** *Lond. Elecn.*, Aug. 16, p. 162.

**Combination Conduit for Cable or Electric Railways, Telegraph Wires, etc.** *Md. Lt. & Ht*, Aug. 29, p. 269. (W. J. Brewer.)

**Underground Electric Cables.** Dr. Werner von Siemens. *Sci. Am. Supp*, Aug. 10, p. 11,342

**Board of Electrical Control.** *West. Elecn.*, Aug. 24, p. 107.

**The Board of Trade Rules for Overhead Wires.** *Lond. Elec.*, Aug. 23, p. 412.

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THERMO-ELECTRICITY.

**The Burton Electric Heater.** (Ill.) *Elec. World*, Aug. 24, p. 126.

**Electricity from Heat.** (Note.) *Lond. Elecn.*, Aug. 30, p. 421. (G. D. Shepardson.)

**Thermo-Electricity Theoretically and Practically Considered.** (Ill.) **II.** Arthur Rust. *Elec. World*, Aug 3, p. 69. **III.** Aug. 10, p. 90.

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ATMOSPHERIC ELECTRICITY.

**Atmospheric Electricity.** (Note.) *Lond. Elecn.*, Aug. 2, p. 318.

**Modes of Damage by Lightning.** (Corr.) J. Lavender. *Lond. Elecn.*, Aug. 9, p. 360.

**An Improved Lightning Protector.** (Ill.) A. R. Bennett. *Lond. Elecn.*, Aug. 16, p. 375.

**Lightning, Lightning Conductors, and Lightning Protectors.** *Jour.* Instn. of Elec. Engrs.; *Lond. Elecn.*, Aug. 9, p. 354; Aug. 16, p. 382; Aug. 23, p. 407.

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**Two Strokes of Lightning.** W. J. Moore. *N. Y. Elec. Engr.*, Aug., p. 341.

**Lightning Conductors.** S. A. Varley. (Cont'd from p. 79.) *Lond. Elec. Rev.*, Aug. 9, p. 148.

**Instructions for Taking Photographs of Lightning.** (Note.) *Lond. Elec. Rev.*, Aug. 23, p. 215.

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## PRIMARY BATTERIES.

**Physician's Office Batteries.** (Ill.) *Elec. World*, Aug. 3, p. 68. (Reitz Medical Set)

**A Powerful Battery.** (Ill.) *Sci. Am.*, Aug. 31, p. 135. ("Experimental Science." G. M. Hopkins.)

**Contribution to the Management of Primary Batteries.** Dr. Leipmann & E. L. Mayer. *Lond. Elec. Rev.*, Aug. 23, p. 201.

**A New Method of Preparing Wooden Battery Boxes.** (Note.) *Lond. Elecn*, Aug. 30, p. 420.

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## SECONDARY BATTERIES.

**A Rehearing Denied in the Accumulator Case.** *Elec. World*, Aug. 3, p. 76.

**Practical Experience with the Storage Battery.** Ch. S. Patterson. *Elec. World*, Aug. 24, p. 126.

**Success of the Storage Battery Cars on the Fourth and Madison Avenues, New York.** (Ill.) *N. Y. Elec. Rev.*, Aug. 24, p. 8.

**A Promising Western Company.** (The River & Rail) *N Y. Elec. Rev.*, Aug. 31, p. 2.

**Storage Battery Factory.** *West. Elecn.* Aug. 3, p. 57. (The Pumpelly.)

**Charging Stations on the Thames.** *Lond. Elec. Engr.; West. Elecn.*, Aug. 24, p. 111.

**Secondary Battery Sub-Stations.** *Sci. Am.*, Aug. 24, p. 112.

**Storage Batteries.** *Md. Lt. & Ht*, Aug. 8, p. 148. (G. F. Barker, Newport.)

**Development and Progress of the Storage Battery.** Wm. Bracken. Nat. Elec. Lt. Assn. *West. Elecn.*, Aug. 17. p. 96; *N. Y. Elec. Rev.*, Aug. 24, p. 3; *Md. Lt. & Ht.*, Aug. 15, p. 183; *Lond. Elec. Rev.*, Aug. 30, p. 248, (Corr., A Reckenzaun.)

**Storage Batteries and Traction.** *Lond. Elec. Engr.* Aug. 30, p. 174.

**Some Results with Secondary Batteries in Train Lighting.** A. S. Brown. Am. Inst. Elec Engrs. *Lond Elec. Engr.*, Aug. 2, p. 88.

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## MISCELLANEOUS.

**An Electrical Census Machine.** *Md. Lt. & Ht.*, Aug. 8, p. 145.

**Electric Weighing Machine.** *N. Y. Elec. Rev.*, Aug. 24, p. 1.

**Edison and his Inventions at the Paris Exposition.** (Ill.) W. J. Hammer. *Elec. World*, Aug. 31, p. 151.

**Electricity on War Ships.** (Note.) *Lond. Elecn*, Aug. 9, p. 345.

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**The Electric Mail Carrier.** (Ill.) *Sci Am. Supp.*, Aug. 10, p. 11,341.

**E. G. Acheson's New Calelectric Generator.** (Ill.) *N. Y. Elec. Rev.*, Aug. 10, p. 4; *Lond. Elecn.*, Aug. 23, p. 406; *Elec. World*, Aug. 10, p. 92; *Lond. Elec. Engr*, Aug. 16, p 125.

**Artistic Fittings.** (Ill.) *Lond. Elec. Engr.*, Aug. 30, p. 172. (The Globe Elec. & Eng. Co.)

**New Electrical Specialties.** (Ill.) *West. Elecn.*, Aug. 31, p. 121. (Elec. Sup. Co., Chicago.)

**New Electric Exploder.** *Lond. Elec. Rev.*, Aug. 30, p. 229

**The Dumais Soot and Spark Arrester.** (Ill.) *West. Elecn.*, Aug. 31, p. 120.

**Electro-Motive Force of Amalgams.** *N. Y. Elec. Rev.*, Aug. 3, p. 9.

**The Slater Process for the Extraction of Zinc from Silver Ores.** *Elec. World*, Aug. 24, p. 131.

**Elihu Thomson's Induction Experiments at the Paris Exposition.** (Ill.) *Elec. World*, Aug. 24, p 127.

**The Heating of Conductors by Electric Currents.** A. E. Kennelly. *Elec. World*, Aug. 24, p. 135; *West. Elecn.*, Aug. 24, p. 112.

**Non-Magnetisable Alloys.** (Note.) *Lond. Elecn.*, Aug. 30, p. 420.

**Aluminum.** *Md. Lt. & Ht.*, Aug. 29, p. 271.

**Should the Duty on Copper be Abolished?** C. A. Brown. *West. Elecn.*, Aug. 24, p. 106; *N. Y. Elec. Rev.*, Aug. 31, p. 8.

**A Noble Metal.** (Corr.) H. C. C. *N. Y. Elec. Rev.*, Aug. 10, p. 7. (Platina.)

**Water Spray Influence Machine.** (Ill.) Geo. Fuller. Phys. Soc. *Lond. Elecn.*, Aug. 23, p. 410; *Sci. Am.*, Aug. 17, p. 100.

**Continental Items.** *Lond. Elec. Rev.*, Aug. 9, p 146.

**Electrical Developments of Western Towns.** *West. Elecn.*, Aug. 10, p. 72.

**A Boston View of the Electrical Industry.** *N. Y. Elec. Rev*, Aug. 10, p. 8.

**Electrical Work in St. Louis.** *N. Y. Elec. Rev.*, Aug. 10, p. 7.

**St. Louis Electrical Exhibition.** *West. Elecn.*, Aug. 3, p. 54; Aug. 10, p. 69.

**The Clambake of the Year.** *Elec. World*, Aug. 17, p. 121; *Md. Lt. & Ht.*, Aug. 15, p. 204; *N. Y. Elec. Rev.*, Aug. 17, p. 5.

**New Physical Laboratory, University of Michigan.** (Ill.) *Elec. World*, Aug. 31, p. 145.

**The Electrical Exhibition at St. John, N. B.** *Elec. World*, Aug. 3, p. 75; *Md. Lt. & Ht.*, Aug. 1, p. 116.

**Reception and Banquet of the Chicago Electric Club.** *West. Elecn.*, Aug. 10 p. 73; Aug. 24, p. 111.

**The Paris Exhibition.** (Ill.) *Lond. Elecn.*, Aug. 16, p. 373; Aug. 23, p. 397; Aug. 30, p. 422; *Lond. Elec. Engr.*, Aug. 2, p. 92; Aug. 30, p. 166; *Sci. Am. Supp.*, Aug. 17, p. 11,356; *West. Elecn.*, Aug. 24, p. 103.

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**International Electrical Conference of 1892.** *Elec. World*, Aug 24, p. 134; Aug. 31. p. 144; *Lond. Elecn.*, Aug. 30, p. 427.

**The Institution of Electrical Engineers and the Paris Electrical Congress.** *Indust*, Aug. 30, p. 207; *Lond. Elec. Rev.*, Aug. 30, p. 232.

**The Birmingham Exhibition.** *Lond. Elec. Rev.*, Aug. 2, p. 129; Aug. 16, p 176; Aug. 23. p. 203; Aug. 30, p. 239; *Lond. Elecn.*, Aug. 9. p. 353; *Indust.*, Aug. 16, p. 162.

**An Interesting Wire Exhibit at the Paris Exposition.** *N. Y. Elec. Rev.*, Aug. 24, p. 6. (Okonite Co.)

**The Chelsea Electricity Supply Company's Installation.** *Lond. Elecn.*, Aug. 23, p. 403.

**High Tension Currents.** (Note.) *Lond. Elecn.*, Aug. 9, p. 344.

**Electrical Execution by Means of an Inductorium.** Emile Berliner. *Elec. World*, Aug. 3, p. 67.

**The Kemmler Electrical Execution Investigation.** *Elec. World*, Aug. 3, p. 76.

**Mr. Gutmann on Electrical Execution.** *Elec. World*, Aug. 10, p. 94.

**The Constitutionality of Execution by Electricity.** Nat. Elec. Lt. Assn. F. A. Wyman, Dr. Otto Moses. *Elec. World*, Aug. 17, p. 106; *West. Elecn.*, Aug. 17, p. 89; *Md. Lt. & Ht.*, Aug. 15, p. 185.

**A 2,200 Volt Shock.** L. S. Day. *Elec. World*, Aug. 31, p. 147.

**A Kansan Favors Carbonic Acid Gas.** (Corr.) J. B. Allen. *Elec. World*, Aug. 24, p. 131.

**Mr. Harold P. Brown.** *Elec. World*, Aug. 31, p. 153.

**Execution by Electricity.** *Lond. Elec. Rev.*, Aug. 30, p. 238; *West. Elecn.*, Aug. 3. p. 60; Aug. 10, p. 71; *N. Y. Elec. Rev*, Aug. 3, p. 2; Aug. 10, p. 8; Mr. Park Benjamin, Aug. 10, p. 11; *Lond. Elec. Engr.*, Aug. 2, p. 85; *Sci. Am. Supp.*, Aug. 10, p. 11, 341.

**The Law of Probability of Error as Applied to the Observed Electrical Resistance of the Human Body.** A. E. Kennelly. *Elec. World*, Aug. 3, p. 73; *Lond. Elec. Engr.*, Aug. 16, p. 132.

**Variable Resistance of the Human Body.** Robert H. Engle. *Elec. World*, Aug. 3, p. 64.

**A Peculiar Ground.** *Sci. Am. Supp.*, Aug. 31, p. 11,394.

**Magnetism in its Relation to Induced Electromotive Force and Current.** (Ill.) Elihu Thomson. *Sci. Am. Supp.*, Aug. 17, p. 11,354

**Electricity as a Factor in Moral and Social Development.** *Md. Lt. & Ht.*, Aug. 1, p. 111.

**On M. H. Hertz's Experiments.** M. Joubert. *Lond. Elec. Rev.*, Aug. 30, p. 229.

**On Contact Electromotive Force.** J. Enright. *Lond. Elec. Rev.*, Aug. 30, p. 228.

**On Actino-Electric Phenomena.** M. A. Stoletow. *Comptes Rendus; Lond. Elec. Rev.*, Aug. 9, p. 144.

**Magnetization of Iron at High Temperatures.** (Ill.) J. Hopkinson. Roy. Soc. *N. Y. Elec. Engr.*, Aug., p. 358.

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**Hertz's Researches on Electrical Oscillations.** (Ill.) G. W. de Tunzelmann. (Cont'd from p. 309) *Lond. Elecn.; N. Y. Elec. Engr.*, Aug., p. 351.

**Electro-Physiology.** M. D'Arsonval. Paris Inter. Elec. Con. *Lond. Elecn.*, Aug. 30, p. 431.

**Mechanical Details of Electrical Machinery.** A. J. Shaw. *West. Elecn.*, Aug. 3, p. 59; *Lond. Elec. Engr.*, Aug. 16, p. 132.

**On a Mechanical Model, Illustrating the Residual Charge in a Dielectric.** (Ill.) J. H. Poynting. *Lond. Elecn.*, Aug. 16, p. 381. (Birmingham Philos. Soc.)

**Plante and the Effects of the Current.** E. A. Le Sueur. *Elec World*, Aug. 31, p. 149.

**The Value of Economic Data to the Electric Industry.** A. R. Foote. Nat. Elec. Lt. Assn. *West. Elecn.*, Aug. 17, p. 81; *N. Y. Elec. Rev.*, Aug. 17, p. 8; *Md. Lt. & Ht.*, Aug. 15, p. 172; *Elec. World*, Aug. 17, p. 101.

**Potential Geometry.** Townsend Wolcott. *Elec. World*, Aug. 31, p. 148.

**Novel Experiments on Light and Electricity.** *Elec. World*, Aug. 3, p. 70. (M. J. Borgman.)

**On a General Law of Induction in Circuits without Resistance.** M. G. Lippmann. *Lond. Elec. Rev.*, Aug. 23, p. 209.

**The Inductance of Unclosed Conductive Circuits.** (Corr.) Oliver Heaviside. *Lond. Elecn.*, Aug. 9, p. 359.

**On Free Ions.** W. Ostwald and W. Nernst. (Concl'd from p. 301.) *Lond. Elecn.*, Aug. 2, p. 323.

**Obituary.** James Clarke Bey. *Lond. Elecn.*, Aug. 2, p. 326.

**Death of George S. Ladd.** *Elec. World*, Aug. 10, p. 82.

**An Important Patent Decision.** *Elec. World*, Aug. 3, p. 67. (Fowler Cast Steel Car Wheel Co.)

---

## MECHANICAL.

**Steam Plants for Electrical Service.** (Ill.) W. H. Bryan. Engrs. Club, St. Louis. *West. Elecn.*, Aug. 31, p. 124.

**Three-Cylinder Engines at the Paris Exhibition.** (Ill.) *N. Y. Elec. Rev.*, Aug. 3, p. 3. (Mr. Brotherhood.)

**Triple Expansion Engine and Dynamo.** (Ill.) *Indust.*, Aug. 23, p. 180.

**Bryant's Automatic High-Speed Safety Engine.** (Ill.) *Elec. World*, Aug. 31, p. 154.

**The New 100 H. P. Straight Line Engine.** (Ill.) *Elec. World*, Aug. 24, p. 132.

**The Castle-Allen High-Speed Engine.** (Ill.) *Elec. World*, Aug. 3, p. 73.

**The New McIntosh & Seymour Tandem Compound Engine.** (Ill.) *Elec. World*, Aug. 3, p. 93; *Md. Lt. & Ht.*, Aug. 1, p. 114.

**Victor Turbines in Electric Light Plants.** (Ill.) *Elec. World*, Aug. 24, p. 130; *West. Elecn.*, Aug. 10, p. 73.

**The Zell Improved Safety Boiler.** (Ill.) *N. Y. Elec. Rev.*, Aug. 31, p. 2.

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**Copper Steam Pipes.** (Corr.) W. Stepney Rawson. *Lond. Elec. Rev.*, Aug. 23, p. 224.

**Steam Boiler Trials.** *Md. Lt. & Ht.*, Aug. 8, p. 137.

**New Positive Locking Clutch.** (Ill.) *West. Elecn.*, Aug. 10, p. 66.

**Pulleys for Electric Light Plants.** (Ill.) *Elec. World*, Aug. 24, p. 130. (Taper Sleeve Pulley.)

**The Tripp Anti-Friction Journal Bearing.** (Ill.) *Elec. World*, Aug. 10, p. 93.

**Bristol's Steel Belt Fastening for Dynamo Belts.** (Ill.) *Elec. World*, Aug. 24, p. 128; *N. Y. Elec. Rev.*, Aug. 24, p. 12.

**New Taping Machine.** (Ill.) *N. Y. Elec. Rev.*, Aug. 24, p. 11. (N. Eng. Butt Co.)

**An Improved Cabinet Turret Lathe.** (Ill.) *Elec. World*, Aug. 10, p. 94. (Lodge, Davis & Co., Cincinnati.)

**New Twelve-Stand Cabling Machine.** (Ill.) *Elec. World*, Aug. 3, p. 71; *N. Y. Elec. Rev.*, Aug. 3, p. 10.

**An Improved Jointing and Facing Machine for Electrical Factories.** (Ill.) *Elec. World*, Aug. 3, p. 74. (S. A. Woods Co.)

**The Eclipse Hydraulic Elevator at the Manhattan Electric Light Company's Station.** (Ill.) *Elec. World*, Aug. 31, p. 154.

**Overhead Cranes in the Westinghouse Factory, Pittsburgh.** (Ill.) *Elec. World*, Aug. 3, p. 72.

**Billings' New Style Beam Caliper.** (Ill.) *N. Y. Elec. Rev*, Aug. 31, p. 3.

**Linemen's Torches.** (Ill.) *Elec. World*, Aug. 3, p. 74. (Walsh Gasoline Torch.)

**The Rau Patent Oil Can.** (Ill.) *Elec. World*, Aug. 24, p. 131.

**Powell's Improved Light Feed Oilers.** (Ill.) *Elec. World*, Aug. 10, p. 86.

**Improved Aerated Fuel Burner for Firing Boilers.** (Ill.) *Elec. World*, Aug. 3, p. 73.

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## Reference List of Leading Authorities Cited in the Index of Current Electrical Literature.

| NAME. | ABBREVIATION. | PUBLISHED, &C. |
|---|---|---|
| Engineer. | *Engr.* | London, 163 Strand, weekly. £1.9. |
| Engineering. | *Eng.* | London, 35–36 Bedford St. W. C.; weekly. £1.16. |
| Industries. | *Indust.* | 358 Strand, London W. C. weekly. £1.12. |
| The Electrician. | *Lond. Elecn.* | London, 1 Salisbury Court, E. C.; weekly. £1 2. |
| The Telegraphic Journal and Electrical Review. | *Lond. Elec. Rev.* | London, 22 Paternoster Row, E. C.; weekly. £1.1.8. |
| The Electrical Engineer | *Lond. Elec. Engr.* | London, 139–140 Salisbury Court; weekly, 17s. 4d. |
| Nature. | *Nat.* | London, 29 Bedford St., W. C.; weekly. £1.8. |
| The Electrical Engineer | *N. Y. Elec. Engr.* | New York, 150 Broadway; monthly, $3 |
| The Electrical World. | *Elec. World.* | New York, 167–177 Times Building; weekly. $3 |
| The Electrical Review. | *N. Y. Elec. Rev.* | New York, 13 Park Row; weekly. $3. |
| The Electric Age. | *Elec. Age.* | New York, 5 Dey Street; semi-monthly, $1.50. |
| Modern Light and Heat. | *Md Lt and Ht.* | Boston, 146 Franklin Street; weekly, $3. |
| Western Electrician. | *West. Elecn.* | Chicago, 6 Lakeside Building; weekly, $3. |
| Electric Power. | *Elec. P'wr.* | New York, 132 Nassau St. monthly, $3. |
| The Electro-Mechanic. | *Elec. Mech.* | Kansas City, Mo; semi-monthly, $2. |
| Practical Electricity. | *Prac. Elec.* | Boston, 620 Atlantic Ave.; monthly, $2. |
| Journal of the Franklin Institute. | *Jour. Fkln. Inst.* | Philadelphia, Franklin Institute, monthly, $5. |
| Science. | *Science.* | New York, 47 Lafayette Place, weekly, $3 50. |
| Scientific American. | *Sci. Am.* | New York, 361 Broadway; weekly, $3. |
| Scientific American Supplement. | *Sci. Am. Supp.* | New York, 361 Broadway; weekly, $5. |
| Mechanics. | *Mech* | Philadelphia, 907 Arch St.; monthly, $1. |
| Railroad Gazette. | *R'd. Gaz.* | New York, 73 Broadway; weekly, $4 20. |
| Street Railway Journal | *St. Ry. Jour.* | New York, 113 Liberty St.; monthly, $2 |
| Street Railway Gazette. | *St. Ry. Gaz.* | Chicago, 9 Lakeside Building: monthly, $2. |
| Light, Heat and Power | *Lt. Ht. and Pr.* | Philadelphia, Drexel Building, weekly, $4. |
| Progressive Age. | *Prog. Age.* | New York, 18 Broadway; semi-monthly, $2 |
| Railroad and Engineering Journal. | *Rd. and Eng Jour.* | New York, 45 Broadway; monthly $3 |

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*A paper read before the 43d meeting of the American Institute of Electrical Engineers, New York, February 18, 1890, and discussion thereon. Vice-President T. C. Martin in the chair.*

# THE PRACTICAL WORKING OF THE ELECTRICAL SUBWAYS OF NEW YORK CITY.

BY WILLIAM MAVER, JR.

Knowing very well the widespread interest that has attended the placing of wires underground in New York City, I have been glad of the opportunity to gather and prepare for presentation to you this evening such data and information relating to that subject as I have thought would be, and as I hope may be, found of the most value.

I observe that our worthy secretary has announced me in the notice of the meeting as the electrician of the Consolidated Telegraph and Electrical Subway Company, and quite correctly so. I desire to say, however, perhaps unnecessarily, that I have prepared this paper in my unofficial capacity, and am, of course, alone responsible for what may be contained therein.

The customary reply to an inquiry as to what is the best arrangement for an electrical subway is, "Build a tunnel under the streets and place the wires on the walls within easy access of workmen and into such a tunnel put also the gas and water mains, etc."

Assuming that this would be a satisfactory solution of the underground question if it could be arranged, let us consider what the cost of such an arrangement would be.

It has been estimated that a subway suitable to contain all the electric wires, gas and water mains of New York City would cost $430.000 per mile. This for Broadway alone, from Bowling Green to Central Park, would mean an outlay of about $2,150,000, and if such a tunnel were to be built throughout the entire route of the now existing electrical subways of New York City, the bill would foot up to nearly $30,000,000.

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This amount, it will, I think, be generally admitted, is virtually prohibitory of any such subway at present, and if that is the case the fact will perhaps make those who have had preconceived ideas in favor of a universal tunnel scheme more tolerant of the electrical subways we have, the practical working of which I am to endeavor to describe this evening.

When the first whisperings of a desire on the part of the public or press to have electric wires in the large cities go underground were heard in this country, it will be remembered the telephone people with one accord admitted that it would be quite feasible for the telegraph and electric light people to operate their wires underground, but claimed that for them to attempt to thus operate their circuits meant irretrievable ruin. Equally convinced also were the telegraph people that while it would be very easy for the electric light companies to work their circuits underground, it was quite out of the question that telegraph wires could be operated successfully in subways, since the increased electro-static and electro-magnetic effects would completely destroy quadruplex and fast automatic telegraphy. And no less emphatic was the opinion of the high-tension electric light people that the telegraph, the telephone and the low-tension electric light systems could, if required, all go underground without detriment, but it was utterly impossible for them to do so and at the same time to operate their circuits successfully.

New York City was no exception when the time came to place the wires underground. Gradually, however, the telephone yielded—more gradually the telegraph, but more tenaciously the majority of the high-tension people clung to their statements, and the experiences of the cities of Chicago and Philadelphia, especially Philadelphia, and elsewhere were cited as evidence of the futility of any attempt to operate high-tension currents underground. These experiences were held to show that no insulation could be procured which would withstand the pressure of the high electromotive force employed on high-tension circuits. In addition to this it was also asserted that the requirements of the Subway Commission regarding the insulation resistance of the underground conductors was high beyond all precedent and unobtainable in practice, and that even if such insulation could be obtained it would be impracticable to make tests of the conductors, showing them to possess the insulation resistance required by the rules.

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It is very far from my intention to go into a history of the opposition offered by the different electrical companies to placing their wires underground, and in-so-far as I have just alluded to it I have done so for the purpose of quoting in a general way some of the reasons given by the companies for this opposition, and this only, that we may see how far the surmises of those who were thus averse to placing wires underground have been verified by actual results.

It is told of a certain noted geologist that when a specimen of gold quartz, which had been found in a locality where he had stated no gold would ever be found, was shown him, he remarked that if it really had been found there, nevertheless it had no right to be there.

I can imagine that there are many persons—perhaps not in this room—but somewhere, who, if told that the telephone, telegraph, high and low tension electric light circuits, and even "deadly" alternating circuits, are to-night in this city working successfully underground in the same streets and on the same side of the streets, would reply, "If they really are working successfully there, they have no right to be."

In preparing this paper I have found that the subject has almost naturally arranged itself under the following general headings, namely:

The type of conduits used in the subways.
The drawing in of cables.
The methods of distribution.
The cables employed in the subways.
Present condition and probable duration of cables.
Joints.
Lead covered cables.
Insulation and tests.
Alleged dangers of the subways.
Gas in the subways.
General remarks.

I have been unable to obtain, with any degree of accuracy, the extent of electrical subways or the amount of wire placed in them in the cities of Europe, and, therefore, I cannot say definitely how New York to-day compares with such cities as London, Paris and Berlin in that respect. But I incline to the belief that it may be found that New York will fall but little, if at all, behind those cities. In New York City, to-day, there are 73 miles

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of electrical subways, and 1,017 miles of ducts. In these ducts there are 10,906 miles of telephone wire, 945 miles of telegraph wire, including fire alarm telegraph wires, and 457 miles of electric light wires. These subways have capacity for about 45,000 miles of telephone and telegraph wires and 2,000 miles of electric light wires.

CONDUITS.

There are in the New York electrical subways eight different conduit systems—namely, the Dorsett, the Wyckoff, zinc tubing in hydraulic cement, sheet iron cement-lined pipe, wrought-iron pipe in hydraulic cement, wrought-iron pipe in asphaltic concrete, the Edison iron tube and the Johnstone sectional cast-iron conduits. All of these conduits have been frequently described; I shall therefore just briefly refer to each.

The Dorsett system consists of blocks formed of a material the ingredients of which are pitch, coal tar and fine gravel. The blocks are moulded, with tubular openings about 2½ inches in diameter from end to end. The blocks are about 4 feet long and 1 foot cross section. These blocks are placed end to end in the trench, and are joined together by pouring between the ends a liquid compound of pitch and tar, which speedily hardens. This compound is prevented from entering the ducts by sleeves, which are placed in each duct between the junction of every two blocks. There is about one mile of this conduit, containing 16 miles of ducts, on Sixth avenue. It is used for telephone and telegraph conductors. This conduit was laid three years ago. So far as I can learn, it is in a fair state of preservation to-day—but not perfect; the blocks having in some instances sunk, and thus put the ducts out of alignment. It may be noted here that guide ropes, consisting of ¼-inch tarred hemp, which were laid in these ducts when this system was constructed, to be in readiness when cables were to be drawn in, show plainly in numerous places signs of deterioration, said to be the result of dry rot, combined with the gases found in the ducts.

The zinc tube conduits are laid in 58th street. The zinc tubing was intended to serve simply as a mould around which hydraulic cement concrete was to be placed, with the expectation that when the zinc had corroded, the tube formed by the solid cement would remain intact. About one mile of this conduit has been in successful operation for three years, but the difficulty attending *the construction* of a conduit formed in this way was so great, owing

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to the frailty of the zinc tube, which readily gave way under moderate pressure, that its use has not been further extended.

The sheet iron cement-lined pipe conduits are made in single or multiple tubes of 2, 4, 6 or more ducts, as may be required and in lengths of 8 feet. The tubes are connected together by a ball and socket joint. These conduits are made as follows; a sheet iron tube 8 feet in length is held vertically; inside of the tube is placed a smaller brass tube, and semi-liquid cement is poured into the annular space between the brass and sheet iron tubes. When the cement has solidified the brass tube is withdrawn. The cement tube is then ready for the subways. There are about 113 miles of ducts of this conduit in the subways, and during the coming summer it is expected many times this amount will be laid in New York City.

There are about 15 miles of creosoted wooden ducts in the subways known as the Wyckoff conduits. These ducts are formed of wooden piping similar to ordinary pump logs. There are lead-covered telephone cables in these ducts, and the action of the creosote upon the lead covering is being carefully watched. These ducts have been in operation for three years. I am informed that detrimental effects are noticeable in the lead covering of the cables, which is alloyed with 3 per cent. of tin.

The bulk of the subway conduits consists of wrought-iron pipe laid in hydraulic cement concrete. These pipes are 20 feet in length and vary in diameter from 2 to 3 inches. The thickness of the iron is .217 inch.

In laying all of these pipe conduits, the bottom of the trench is first levelled to grade; planks are then set against the side of the trench to sustain it. A layer of concrete is then laid and rammed in the bottom of the trench. On this is placed a row of iron pipe, next a layer of concrete, then another row of pipe, and so on, until the desired number of layers is attained. The number of pipes in a row depends upon the topography of the street and the location of existing gas and water pipes which it is desired to avoid, and the number of rows upon the total number of pipes desired to be laid in a given subway. In order to add strength to the mass and to protect the ducts from mechanical injury, the concrete is applied more thickly on the bottom, top and sides of the subway than between the pipes. There is placed over all a two-inch yellow pine planking, heavily creosoted, to further protect the conduits against injury from picks, crow bars, etc., in the event of future excavations in the streets. (See Fig. 1.)

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The wrought-iron pipes are joined end to end by a coupling screw joint with a tapering or vanishing thread. By the use of this form of thread, I am informed the rate of laying this piping is increased 50 per cent. These tubes are delivered free from burrs and have a smooth inner surface. The pipes are sometimes asphalted to prevent rusting, but should they in the course of time rust, it is expected, as in the case of the zinc tube, that the concrete will preserve the shape of the duct intact. There are close upon 550 miles of wrought-iron piping in the subways.

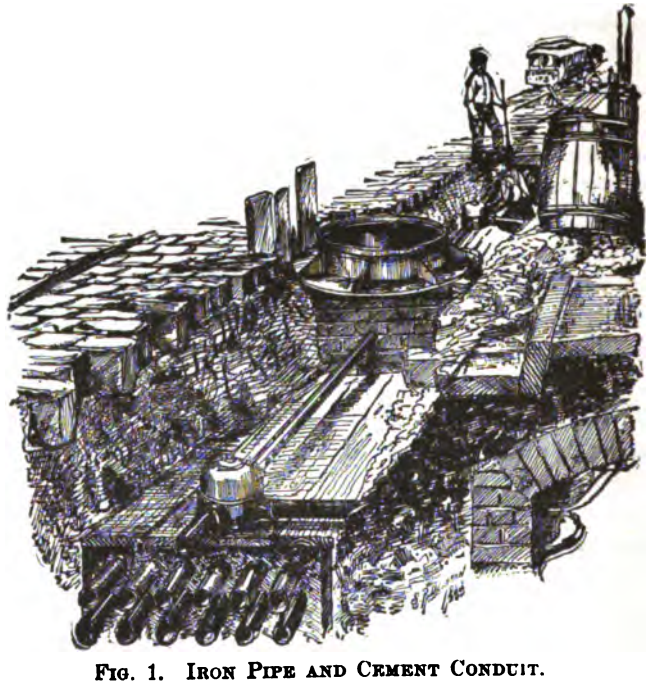

FIG. 1. IRON PIPE AND CEMENT CONDUIT.

The facility with which a pipe conduit conforms to the varying condition of the crowded streets of large cities, as found in the process of trenching, is one of its chief advantages.

The main reasons which have led to the extensive use of wrought-iron piping in the subways are its great strength, its adaptability to varying conditions of the street and the rapidity with which it can be laid.

The Edison system consists of wrought-iron pipe in which are placed the copper conductors or rods. These conductors are wound with rope and the pipe is filled with an insulating com-

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pound of Trinidad asphaltum, rosin, paraffin and linseed oil. These iron pipes are laid directly in the earth. There are about 50 miles of this pipe now laid in New York City.

The subways are in many cases on both sides of a street, and, as a rule, the telegraph and telephone wires are assigned to ducts on one side of the street, and the electric light wires to ducts on the opposite side; but in numerous instances the electric light wires are operated in distributing ducts on the same side of the street as the telegraph and telephone wires, and without detriment to the latter. In no case, however, do the telegraph and telephone ducts inter-communicate with the electric light ducts, and separate manholes are provided for each.

### MANHOLES.

Access is to be had to the conduits of the New York subways by means of manholes, placed at an average distance of about one-twenty-fifth of a mile apart. The manholes are, with a few exceptions, built of brick laid in concrete cement, with hydraulic concrete bottom. The outside of the walls is coated with cement, to prevent moisture and gas from penetrating.

Access to the manholes from the street is had through the cast-iron head which is set on the brickwork and which is provided with double covers. The upper or street cover weighs about 350 pounds. The lower cover is provided with a rubber gasket to prevent ingress of street water into the manhole. This cover is funnel shaped in order that any water which may enter through the upper cover may be drained away from the gasket. The lower cover is screwed down upon the gasket by a gun metal bolt and cross bar. The upper cover is loose upon its bearings. The ducts enter the manholes at a point easily accessible to the workmen while standing on the bottom of the manhole. The manholes average in width about five feet and vary from five to ten feet in depth. The drawing, Fig 2, shows a standard manhole of the New York subways. The hand blower used for driving out gas from the manholes is shown, also the iron framework or cage which is placed around the opening to the manholes when the cover is removed.

The foregoing mentioned conduits may be considered as belonging to the regular subway system of New York City.

There are, however, several other conduits in operation in this city, namely, the Brooks, the Western Union, and about five

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miles of telephone cable laid in wooden boxes filled with sand. The Brooks system has been so repeatedly described I need not further allude to it. The Western Union subway consists of an iron pipe about six inches in diameter into which wires have been drawn.

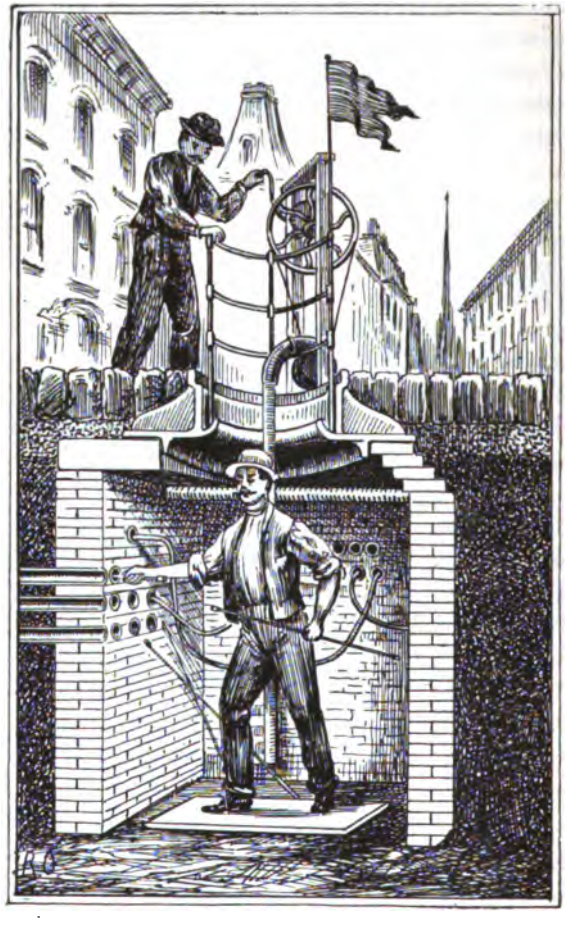

FIG. 2. STANDARD MANHOLE.

RODDING.

The electrical subways of New York City, with the exception of the Edison system, are of the class known as the drawing in and out systems. The first process in drawing a cable through a duct which is not easily accessible except at its ends in the manholes is obviously to provide a means of drawing in the cable.

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This is done by a process technically termed rodding, which consists of pushing rods through the duct from one manhole to the next. A rope is then attached to the end of the rod and the rod is withdrawn bringing the rope with it. This rope is then employed to haul in the cable. As some of the manholes are over 500 feet apart, and it would not be convenient to procure a continuous wooden rod of that length, rods of about four feet in length, furnished at one end with a screw and at the other end with a screw socket, are used. These are placed in a bunch in the manhole and are attached by the screws one to the other, as many as are required to reach to the distant end of the duct. The rods are then detached, as they are drawn out, by unscrewing the ends. This is a specimen of this form of rod. (Showing.) It is the one most generally used. There are other forms of rod also in use in the subways. This (showing) is one of them. It is furnished with a slot into which the T end fits, but into or out of which it can only go at a certain limited angle. Therefore, while this joint or connection is quite loose, there is no likelihood of the rods coming apart in the duct because the diameter of the ducts does not permit a sufficient movement of the rod at the joints. The time taken in rodding a duct 300 feet in length is about 20 minutes.

A continuous steel wire rod about one-quarter of an inch thick and from 400 to 500 feet long is also used for rodding the ducts. This rod is mounted on a reel about 6 feet in diameter, which is placed adjacent to a manhole, and from which it is reeled off as it is pushed through the duct. When this operates freely, it is more expeditious than the wooden rod methods just described, as the time taken in jointing up the rods is saved; but it is found that the wire occasionally buckles in the duct, and, furthermore, it is more apt to be caught by any obstruction or unevenness, than are the wooden rods, so that by many the latter are employed as being the more expeditious, all things considered.

There is also another means of rodding sometimes employed, which consists of a long spiral steel rod, the spiral of which is about one inch in diameter. On the circumference of the spiral small wheels are mounted to ease the friction. This rod is also placed on a reel and wound off as it is fed into the duct. This spiral, while quite elastic, is yet capable of withstanding considerable pressure. This rod is pushed into the duct in the usual way. The expense and the weight of this form of "rodder" is some-

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what against it, although I am informed that by its use a duct can be rodded in one half the time required by the screw rods.

Before those employed in the work of drawing conductors into subways had devised and settled down to the forms of rods just described, many bright minds were at work on the question of how to rod the ducts. The scheme of tying a string to a rat's tail and sending him through the duct with a ferret after him was tested practically in Brooklyn, I believe, but the plan was not generally adopted. In the case cited, it is stated that the ferret overtook the rat, and stopping to eat him, was overcome by the gas and asphyxiated. This necessitated the tearing up of the street to get at the remains.

In Chicago, it was seriously suggested that a wooden ball with a string attached to it be placed in the duct, and that then a hose connecting with a neighboring hydrant be inserted in the duct. The water was to force the ball through the duct. This plan was found to work successfully so far as getting the ball through was concerned, but it flooded the manholes, and was not put into general use, even in Chicago.

Another inventor devised what he called a mechanical creeper, which was designed to advance itself through the ducts by putting out arms against the walls and thus pushing itself along.

Sometimes, in rodding, obstructions are met with, caused by pieces of cement, stone, dirt, etc., gaining access to the ducts. Sometimes, also, obstructions are caused by uneven joints in the conduits. Ordinary obstructions are removed by a mandrel placed on the first rod.

### DRAWING IN CABLES.

After the rope has been attached to the cable, the latter is then "threaded" through the duct. The attaching of the rope to a cable is a matter of some skill. The connection is so made that the strain comes chiefly on the conductors. To prevent the cable or cables from twisting as drawn in, a swivel is inserted in the rope near the cable.

The manner of applying the force necessary to pull the cable through the duct depends upon the size and length of the cable. If it is a small cable, say 300 feet in length, it can be drawn in by two or three men. If it is a large cable, or if four or six small cables are to be drawn into one duct, as is frequently done, more elaborate drawing-in apparatus is used. This generally consists of some form of winch, such as is shown in Fig. 3, which very

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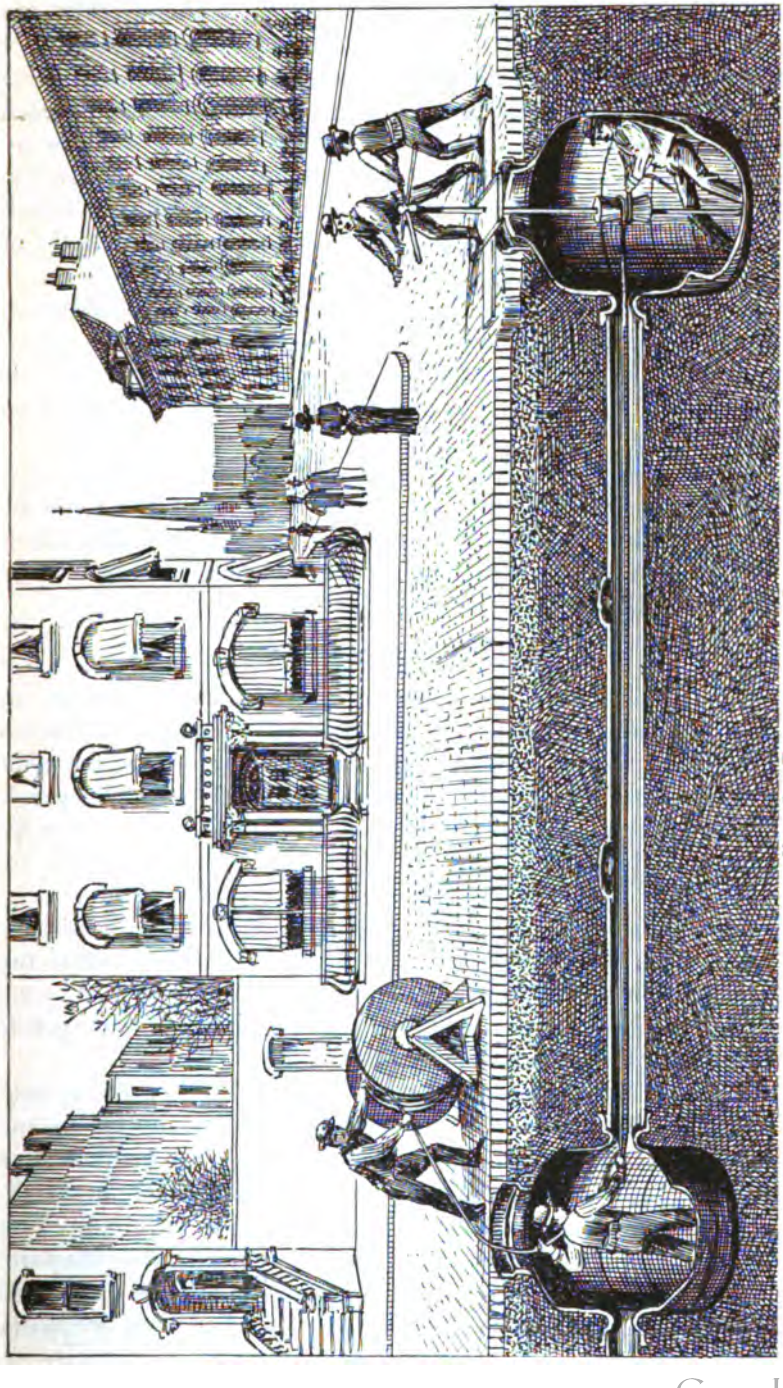

FIG. 3. DRAWING IN A CABLE.

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well illustrates the method. The largest telephone cables are drawn in by a winch of special construction, in which the power is transmitted through the intervention of wheel gearing. As a rule, it may be said that in the matter of drawing cables into the ducts the work has been satisfactorily performed. In a few instances mistakes have been made, as in the attempt to draw too many cables into one duct—the old problem of putting a 3-inch bung into a 2-inch hole—and in the attempt several lengths of cable have been jammed in the ducts and injured.

As many as six electric light cables, No. 4 B. & S. conductor, have been repeatedly drawn at once into a 3-inch duct.

It is not deemed advisable to draw cables into or out of ducts over cables already laid, but in cases of necessity it has been done without injury to the cables.

As the weight of a No. 4 B. & S. lead covered cable, is for 300 feet, say 250 pounds, an idea may be obtained of the force required to draw in six such cables. I am informed that cables weighing in the aggregate 5,510 pounds have been drawn at one time into one duct.

### METHODS OF DISTRIBUTION.

It is, of course, a comparatively easy problem to arrange an electrical subway for trunk line circuits. The difficulty arises when the question of distribution of the current from the main conduits is to be considered, as when, in the case of the telegraph and telephone service, it is desired to furnish customers with circuits, and in the case of electric light service when it is required to make house to house or street lamp connection.

In the case of telegraph and telephone distribution subsidiary pipes or ducts are generally led from an adjacent manhole to the front or side of buildings, whence the cables are continued to the roof of the building or to the back yards, from which latter points the circuits are radiated as required.

The cable of the telephone company is generally made up into 50 pairs When this number of circuits is not needed in one block or series of blocks, the cable is forked in the manhole, one portion of the conductors being led in a smaller cable in one direction, another portion elsewhere, as may be required. This method of distribution has been found convenient and satisfactory.

Distribution of the electric light current is effected in several different ways in the New York subways. For street arc lamps

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the circuit is usually looped from the manhole to the lamp post through a subsidiary iron pipe.

For easy access to houses and to lamps in the middle of blocks distributing ducts are laid above the trunk ducts as near the surface of the street as practicable. The average distance from the surface of the street being perhaps 18 inches.

The Johnstone sectional conduit, Fig. 4, has hitherto been the

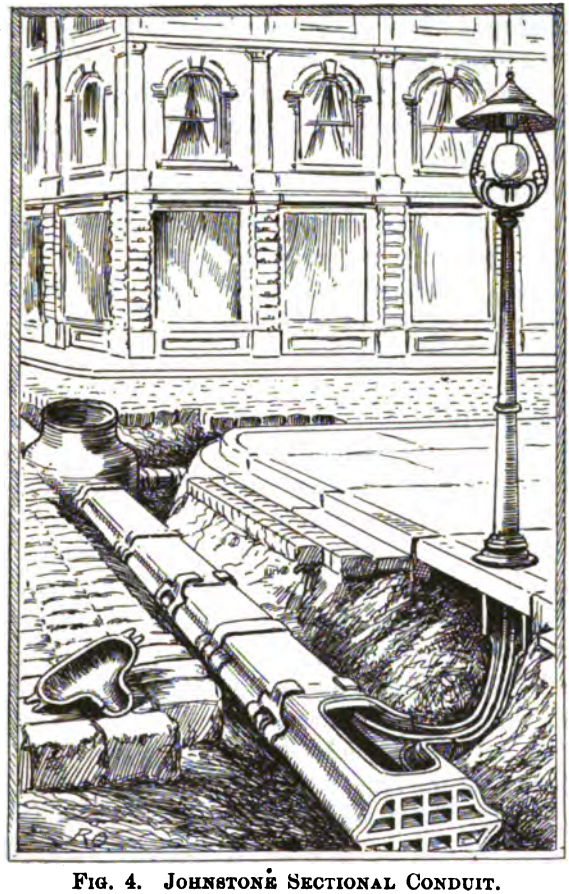

FIG. 4. JOHNSTONE SECTIONAL CONDUIT.

most extensively employed for this purpose in New York City. This conduit consists of sections of cast-iron ducts about 5 feet in length. The sections are placed directly above each other and are held together when in position by removable clamp pins. The upper section rests in a groove in the lower section. Each section of the conduit is divided into from two to six or more

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compartments or ducts—depending upon the size of the section —the ducts being formed by removable partitions or slats held in position by suitable channels or grooves within the sections. Opposite each house or every alternate house a "handhole" is provided in the upper section of the conduit. This handhole consists of a removable cover, about 2 feet in length, on the upper section, and the side of the section at this point is provided with a branch or spigot.

This conduit is laid directly in the earth—not in cement. When it is desired to obtain access to a conductor to tap or loop the circuit into a building, the paving and earth are removed from the street and the cover of the handhole is lifted, thus exposing the conductors in the ducts. A 3-inch iron pipe is run from the branch at the handhole to the basement or vault of the house or to the lamp post with which connection is desired to be made. This iron pipe fits onto the spigot at the side of the conduit. The connection is then made with the conductors by splicing on short lengths of cable leading through the iron pipe to the house or lamp. Should the conductor which it is desired to tap be at the side of the section remote from the spigot, the intermediate partitions are removed to permit the passage crosswise of the connecting cable. After the joints are made, the cover of the handhole is replaced and the earth and paving are restored to their normal condition.

When a handhole has not been provided originally at a point where access is desired to a conductor in the conduit, the entire upper section is removed and replaced by a half section containing a handhole cover and spigot. This work can be done in a short time. The sections in use for this purpose are, in some instances, somewhat small for ease in joint making, especially, as but very little slack is available when T joints are to be made, and, in future, larger handholes will be provided. These conduits are presumably made air and water tight at the junction of the two sections and, at the ends of the ducts, by the use of plumbers' putty. In view of the number of supposed opportunities for the entrance of moisture at these junctions, it would be naturally expected that this type of conduit would be in a chronic moist condition. Indeed it has been predicted of it that the ducts would act as canals for the surface water; but, as a matter of fact, these ducts are almost invariably dry. There are two theories given to explain this fact. The first, that in reality the

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plumbers' putty makes an air and water tight joint. The second, that if the joints are so imperfect as to admit water, they are quite capable of permitting its escape also. It must be said that this system has been found of much utility in the practical distribution of electric light current in this city.

More recently a method of distribution in which wrought-iron pipes are used has been employed. This consists of a row of three or four iron pipes laid, like the Johnstone conduit, as near the surface as possible—in the earth, without concrete. Opposite every party wall, or, in other words, at distances of about 50 feet apart, iron boxes about 18 inches square are placed. These boxes have removable covers. The ducts enter at the ends of the box but do not pass through it. The boxes are provided with side openings also for the entrance of the subsidiary iron pipes. Access is had to these boxes also by the removal of the street paving and earth.

This method of distribution has, like the one just described, been found satisfactory. Certain mechanical improvements in the construction of both are, however, desirable, and are contemplated. (See Fig. 5.)

When it is desired to cross a street to reach customers subsidiary ducts are constructed.

It is frequently remarked, presumably derogatory of the existing electrical subways, that no system of house to house distribution can be considered perfect which requires the tearing up of any portion of the street to obtain access to the mains. This will be granted by any one. The same is equally true of the house to house distribution of gas and water from the street mains. In all of these cases, if the connections were made from the street mains to every house and vacant lot along their routes when the mains are first laid, the necessity for reopening the streets to make house connections would be avoided. But I have yet to learn that this is done by either the gas or water companies, nor have I heard that their neglect to do so has been seriously animadverted upon.

It would, therefore, seem unreasonable that the additional expense of making these connections, which may never be required, should be urged upon the users of the subways by any who have the interest of electrical industries at heart, especially while they ignore the failure of the gas and water companies to make corresponding connections.

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THE CABLES EMPLOYED IN THE SUBWAYS.

In the telephone service in this city, the cables used are chiefly of the type known as the Patterson. This cable is constructed as follows: Ordinary cotton covering is first placed around the wires. After the wires are cabled, a lead covering is placed over

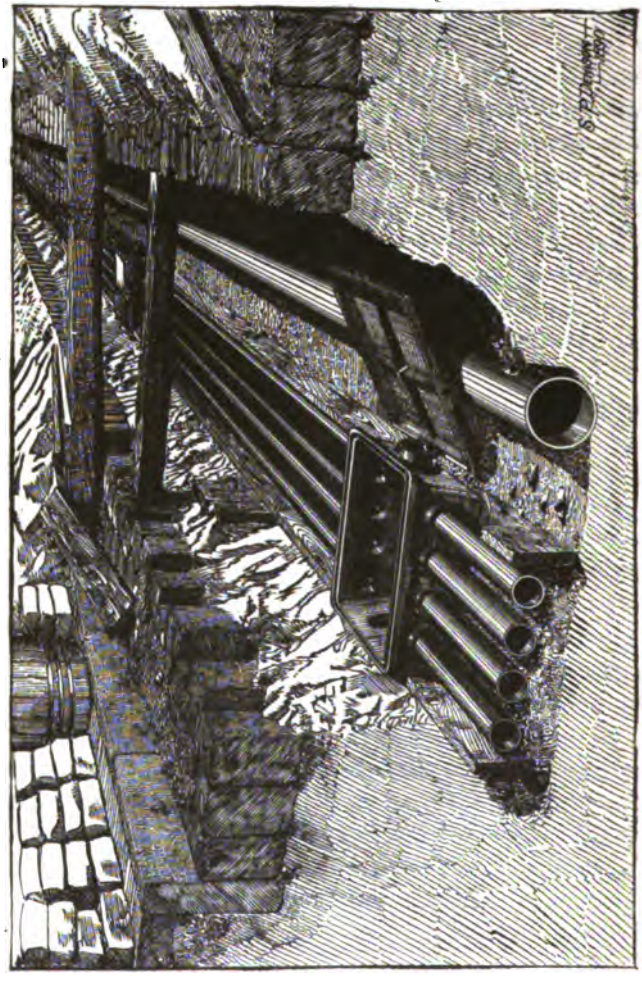

FIG. 5. DISTRIBUTING DUCTS AND AIR PIPE.

them, and paraffin is then forced into the interstices between the conductors and lead covering.

This cable has an electro-static capacity of about 0.16 microfarad. The insulation resistance of the cable, laid and jointed in the subways, averages about 100 megohms. The longest stretch

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of cable used by the telephone company in the subways is seven miles. The greatest number of conductors in any one cable is 100 or 50 pairs.

The telephone service on the underground conduits was impaired somewhat, so long as ground circuits were used, but since the adoption of metallic circuits the service is satisfactory. On the long distance telephone circuits the seven miles of cable is, of course, somewhat detrimental. It is said the loss of efficiency on such circuits is 30 per cent.

The telegraph companies have thus far used chiefly for underground service Kerite, Okonite, Standard Underground and Patterson cables. The Kerite and Okonite insulation, it is well known, are homogeneous compounds. These cables are not lead covered. Of course they could be. The Standard and Patterson are fibrous cables and are lead covered.

Except in the vicinity of the underground steam pipes, the unprotected homogeneous cables have given satisfaction. But as might be expected, the effect of a continued high temperature upon them has been detrimental.

Fortunately the heated area in the vicinity of the electrical subways is limited to a portion of the down-town districts. Investigation has shown that the heat only reaches a harmful temperature in the neighborhood of actual leaks in the steam pipes. Measurements of the temperature of a manhole in the worst section of the heated district have shown as high as 150 deg. to 200 deg. F. Since the starting of the blowers in this district to ventilate the subways, a noticeable decrease in the temperature is observable, and, inasmuch as the steam heating company is achieving some success in its efforts to close up all leaks in the pipes, it is anticipated that the heat difficulty will be eventually removed from the subways.

The users of the Standard and Patterson cables state that those cables are giving very fair service in the heated portions of the subways, although the high temperature, of course, very materially lowers the insulation resistance of the cables.

The average number of conductors in the telegraph underground cables is about 50. The size of the wire used is, as a rule, No. 16 B. W. G. and the outside diameter of a conductor, including the insulation, is 6-32 of an inch. The insulation resistance of the Okonite insulation is about 2,500 megohms; that of Kerite 500 to 800 megohms and that of the Standard and Patterson

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about 1,500 megohms per mile for the thickness of insulation just mentioned.

Outside of the injury to the cables due to the presence of the steam-heating pipes, no undue deterioration of the telegraph cables in the subways has been noted.

The increased electro-static capacity of the underground circuits has not caused any marked inconvenience in the operation of the telegraph circuits.

The comparatively low mileage of telegraph wire in the subways is partly explained by the fact that the bulk of the telegraph circuits in New York City are suspended from the Elevated Railroad structures.

The Fire Alarm Telegraph cables in the subways do not differ very materially from those used by other telegraph companies. The Fire Department thus far has used Standard Underground cables.

ELECTRIC LIGHT CABLES IN SUBWAYS.

In the electric light service in the subways, and I am aware that it is around this that the greatest interest centres, there are, exclusive of the Edison, four different types of cable used—namely, the Bishop Rubber Compound, the Standard Underground, the Safety Insulated and the Cobb Vulcanite Paraffine cable. All of these cables are lead covered as a precaution against mechanical injury, action of acids, etc., or moisture. Specimens of these cables are on the table.

The sizes of conductors used in the electric light service vary with every company and with the character of the service. For feeders the conductors range in size from No. 000000 B. & S. to No. 2 B. & S. For mains from No. 2 to No. 6 B. & S. In many instances No. 10 B. & S. is used for connecting from the mains to lamps through the subsidiary ducts.

The Standard Underground Cable.—The insulation of the Standard Underground cable is obtained by first wrapping thick cotton thread or cord around the wire to any desired thickness. The wire thus covered is then placed in a cauldron of boiling insulating compound—a product of petroleum. This treatment displaces any moisture that may be in the cotton thread. After the cotton has been thoroughly saturated with the compound the whole is then lead covered.

There are now in actual service for electric lighting purposes in the New York subways over 95 miles of this cable, forming

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parts of currents having an E. M. F. of from 300 to 3,000 volts, including many 1,000-volt alternating circuits, and an additional 50 miles of the same cable will shortly be in operation. The thickness of insulation used in these cables is 5-32, 6-32 and 7-32 of an inch. This refers to the thickness of the insulation from any given point of the circumference of the conductor.

THE "SAFETY" CABLE.—The insulating material of the Safety cable is an india-rubber compound. It differs somewhat, I believe, from the ordinary run of india-rubber compound cables in that the compound is placed over the wire, without seams or laps of any kind. This compound is vulcanized to a moderate degree of hardness sufficient to prevent decentering of the heavy conductors which it insulates, but yet it retains a high degree of flexibility.

The thickness of insulation used on No. 4 Brown & Sharpe wire—.204 inch diameter—is .108 inch. The weight of this conductor, lead covered, is 4,861 pounds per mile. Of this the wire weighs 665 pounds, the insulation 669 pounds, the tape 95 pounds, the lead covering 3,432 pounds.

A special thickness of this insulation was made in one instance in response to a call for cable to withstand a strain of 7,000 volts for arc lighting. A sample of this cable is on the table—the thickness of the insulation is .238 inch. The conductor is No. 4 B. & S. gauge. This cable is now in the subways. Its length is about three miles. I am not aware that it has yet been called upon to withstand the prescribed 7,000 volts.

There are now over 65 miles of the Safety cable in actual use in the subways, assigned to electric light circuits—continuous and alternating—of from 1,000 to 2,500 volts E. M. F., and about 15 miles additional are now being placed in subways.

THE BISHOP RUBBER COMPOUND CABLE.—The Bishop Rubber Compound Cable is of the well-known Silvertown type, having first a coat of rubber without sulphur, then a coat of rubber compound with sulphur, and over this a lapping of rubber cable, which is then taped. There are two sizes of this cable in the subways; namely: No. 4, B. & S., and No. 6, B. & S. The thickness of the insulation is 4-32 inch; the thickness of the lead covering is 5-64 of an inch, the outside diameter of the cable is .65 of an inch, and the weight of the cable is about 4,600 pounds per mile. There are of this cable, in successful operation, about 10 miles assigned to alternating circuits of 1,000

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volts, and five miles to arc circuits of 2,500 to 3,000 volts E. M. F. Double this amount of this cable will soon be laid for similar purposes.

THE COBB VULCANITE-PARAFFINE CABLE is of a somewhat unique construction and design. It also differs materially in one respect from the other cables described, in that the conductor is freely movable within its insulating medium. The cable is made in practically the following manner: A vulcanite tube is first made in lengths of about 300 feet. This tube is moderately flexible. The tubing is vulcanized in boiling paraffine. The wire is then threaded through the tube, after which the sections of tubing are jointed together. A thick cord is then wound spirally around the vulcanite tube. The whole is then lead covered, and the space between the vulcanite and lead formed by the spirally wound cord is filled with paraffine.

There are about twenty-five miles of this cable in the subways.

In the case of the Bishop, Safety, Cobb and Patterson cables, the lead is alloyed with about 3 per cent. of tin. The lead covering of the Standard Underground cable is unalloyed, but it is covered with a thick cotton braiding soaked in "P. & B." paint (the latter a product of petroleum), which, it is claimed, will protect the lead from acid, gases, etc., and the braid also acts to protect the lead from mechanical injury.

### CONDITION OF THE CABLES.

I may say that all of these cables are guaranteed by the manufacturers for three years. This term, however, is not to be taken as signifying the limit placed upon the life of the cables by the manufacturers.

It is over a year since current was turned on the first high tension electric light circuit in the New York subways. This was a circuit in One Hundred and Twenty-fifth street, belonging to the Harlem Electric Light Company. The insulation resistance of the cable, as measured just before the turning on of the current, showed it to be 1750 megohms per mile. A test made of the same circuit last week, after one year's continuous service showed it to have an insulation resistance of 1516 megohms per mile. Since the installation of the circuit just referred to, electric light cables of the various types described have been drawn into the subways almost as rapidly as they could be manufactured, and test made of the conductors months after the initial test has

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shown them to be in the same electrical condition as when first laid.

There have been several burn-outs in cables in the subways within the year, but with the exception of an abandoned type of cable, to which I shall refer later, these burn-outs have been traceable in every case to defective joints or to mechanical injury. In all, according to the records and best obtainable information, there have been, exclusive of those in the abandoned cable, but five burn-outs in over 185 miles of electric light wire during a period of active service of the conductors ranging from one month to thirteen months.

In the case of 27 out of 34 of the electric light circuits in the subways, not a single defect of any kind has occurred since they were placed in the ducts. There have been several instances where faults not amounting to burn-outs have been discovered by the regular tests which have brought the insulation resistance of certain conductors below the requirements of the rules of the subway, but these defects have generally been located and removed without serious delay to the circuits. Where this has not been the case, it can be fairly attributed to the employment of untried insulation, unfamiliarity with underground service, or to the inexperience of the men to whom the work of connecting up circuits, etc., has been intrusted. For instance, in a number of cases grounds have been traced to contact of the conductor with the lead covering and the linemen so connecting them have explained that they were not aware the lead covering would cause a ground.

On several occasions grounds have been caused by the driving of nails through the lead covering of the cables or leading-in wires, under the molding inside of buildings, and on another occasion a ground was caused by a laborer's pick-ax while excavating for a new subway which crossed an existing subway. It is related of the laborer that when he saw the smoke arising from the burning insulation he first tried to put out the fire by throwing water over the cable and subsequently by throwing wet mortar around it.

It is perhaps not remarkable, in view of all the circumstances, that anything in the shape of an electric wire is looked upon by outsiders with serious apprehensions. It has sometimes been amusing to notice the wide berth given even the leading-in wires used during the making of tests of cables by the occupants of buildings from which the test is being made.

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On one occasion, while a test was being made in the basement of the Hotel Brunswick, it happened that the leading-in wires were lying on the floor near by a small pool of water in a hallway. A servant, seeing the water and the wires in close proximity, called out in alarm to one of her companions who was approaching: "Take care, Mary, the electricity is running out."

DEFECTIVE CABLES.

In the case of the cable previously referred to as having been abandoned, the burn-outs were of almost nightly occurrence. The delays to the company using this cable were necessarilly vexatious, and I may say that in my references to burn-outs, defects, etc., occurring in underground cables, I have not included those that were due to the use of this seemingly inherently defective cable. This was a lead covered cable with a vulcanite tube as an insulating medium. This special cable has, I believe, been abandoned, and is no longer in service in the New York subways. What may appear a singular feature in connection with the burn outs in this cable was the fact that the cable had a higher apparent insulation resistance than any other cable in the subways, and would frequently, on a test, show an insulation resistance of over 4,000 megohms per mile a few hours before the occurrence of a burn-out. The same cable showed even a higher test at the factory, namely, about 20,000 megohms per mile. In the latter case it was tested with 400 volts. Burn-outs on this cable have occurred when the pressure employed on the circuit did not exceed 600 volts.

The explanation of this may be that owing to the nature of the insulating material and to the fact that it was not tested under water before being lead covered, there may have existed fractures in the vulcanite tubing, or such fractures may have been caused in process of drawing the cable into the ducts. Under the tests made with the 100 and 400 volts E. M. F. of the testing battery, a fault would not develop; under the high electromotive force of the dynamo and the current of 10 or 12 ampères, the fault would develop, perhaps due to moisture of condensation of the air in the tubes caused by the heating of the wire. This explanation is apparently confirmed by the fact that 25 miles of a somewhat similar cable, namely, the Cobb cable, which I have described, but in which paraffine is placed between the lead covering and the vulcanite tube, has been in successful operation in the subways for

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high-tension circuits for over two months without any indication of a defect having occurred.

It was rather unfortunate that the cable which I have said has been abandoned as unsatisfactory, and which has indeed been withdrawn from the subways, appears to have been the only cable used for electric lighting purposes in the New York subways which came to the notice of an English electrical engineer during a flying visit to this country, and a description of which cable he presented to our sister society in London in a recent paper, with a favorable prediction as to its probable success.

### LOCATING FAULTS.

The method employed for locating faults in electric light conductors in the subways is to test the conductor from point to point until the defect is placed between two lamps or manholes. When a fault is located between two lamps or two manholes, if it is in the cable proper and not in a joint at a hand-hole or box, the defective section is withdrawn, and a perfect section put in its place. With the exception of the hard rubber cable referred to, this has, I believe, been necessary but on three occasions after the current has been turned on the circuit; in two of these cases the defects were caused by improperly made joints. In the other case by a mechanical injury.

In the case of arc light or series circuits, defects in the cables are more readily located than in multiple arc circuits, because of the facility afforded by the openings at the lamps for testing the conductor in sections. In the case of multiple arc circuits there is at present no means of locating faults but by cutting the conductor in manholes. For, as the house connections are made from the cable by T joints, it is obvious that the only effect of disconnecting the lamps or converters from the cable is to separate the two conductors of the circuit. These remarks, it is understood, do not apply to the Edison conductors, to which it is well known access is had at the ends of each pipe by removing the paving and earth above the pipe.

No attempt is made to locate faults in electric light circuits in the subways by electrical measurements, for the reason that the obstacles in the way of obtaining accurate data are so numerous that it has not been considered expedient to rely on the results of such measurements. For instance, the uncertainty as to the distribution of the resistance of the conductor owing to the numerous

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joints in the circuit, the variations in temperature of the subways and the difficulty in ascertaining it, etc.

To facilitate the locating of faults, should they occur in the subways, several forms of accessible joints have been suggested for use in the manholes. One of these, known, I think, as the Dillon joint, consists of a metal cup, having in its bottom, apertures through which the cable ends pass. The lead covering of the cable is soldered into the cup, the conductors are connected or spliced, and insulated, and a water-tight cover is screwed over the cup.

Another accessible joint, known as the Cobb joint, is made as follows: A copper disc is soldered on the ends of the conductors to be connected. Over the discs a vulcanite sleeve is placed. Two shoulders having respectively a right and left hand screw are placed, near the sleeve, over the insulation of the conductor. The sleeve is provided with a right and left hand thread. The forward movement of the shoulders is checked by discs on the ends of the conductors Thus when the sleeve is screwed on to both shoulders the tendency is to press the two discs together tightly. This joint can be made quickly, but as to its practical utility it is not possible to speak definitely as yet, since it has not been in actual service in the subways, so far as I am aware. The same is true of the Dillon joint.

It is perhaps a debatable question whether easily accessible joints are desirable in the manholes of subways, as the tendency in such cases might be to lead to accidents by the exposure of live wires.

### DURABILITY OF CABLES.

Concerning the much discussed question as to the relative durability of rubber compound and fibrous cables, I do not think sufficient time has elapsed in the case of the cables in the New York subways to enable one to arrive at a definite judgment. In the case of both types of cable, as I have already said, many circuits have been running continuously for over nine months, and in some instances for over one year, without a defect of any kind, electrical or mechanical, having occurred, and the slighter defects that have occurred on other circuits have as yet been so few in either type of cable as not to certainly show any marked superiority of one type over another. Specimens of cable that have been examined after nine to twelve months service show no physical or electrical signs of deterioration of the insulation.

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As regards the question as to which kind of cable will best withstand the heat from steam pipes adjacent to the subways, it would appear thus far that the lead-covered fibrous cable is superior to the homogeneous cable *not* lead covered. Lead-covered rubber compound cables have not as yet been tried in the heated districts.

### MULTIPLE CABLES.

There are no concentric cables in the subway in this city. The mains of multiple arc circuits are operated in separate lead covers in the same duct. It is contemplated, I believe, by some of the companies to use one lead cover for such circuits hereafter. One objection on the part of the companies to the use of concentric cables is the anticipated difficulty in making joints, especially where frequent connections for distribution are required. This objection should not hold good in the case of the feeder portion of the circuits.

As to the use of multiple cables for electric lighting, one such cable, a fibrous cable, having eight conductors under one lead cover, was placed in the subways, but has not been operated as yet, trouble having been found in making perfect joints. I have no doubt that with the experience since had in joint making, this difficulty would be overcome, but it seems to be the general opinion that the use of multiple cables is not advisable in electric lighting.

On the subject of loss due to increased electro-static capacity or to increased self-induction of conductors in the subways, I may say that I have made careful inquiry of superintendents of stations where the alternating current is used and learn that no perceptible difference in the operation of the circuits as compared with similar circuits overhead is noticeable. I have been informed that in wet, stormy weather a decided improvement is observable—in fact that the condition of the weather does not affect the circuit. This will be the more readily understood when it is stated that a recent test made during the prevalence of a drenching rain storm, of an arc circuit in the subways four miles in length, showed an insulation resistance of 2,400 megohms per mile. The lamp connections were disconnected from the cable proper during the tests, so that all the terminals of the cable were under cover.

### JOINTS.

When it was urged upon the electric light companies of this city that they were not using due diligence in placing their wires

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under ground, the companies retorted that they were doing so as rapidly as possible consistent with good workmanship, and they cited the fact that it was not possible to joint up the cables more expeditiously than was being done with the number of capable jointers at their command. To this an official of the city replied that this did not, in his opinion, constitute a valid excuse while so many poor men were idle who would be only too glad to be given work at jointing the cables.

This was the view of a layman, but it would seem that in a number of instances in the electric light service in this country somewhat similar views, namely, that anyone could make joints and that any kind of joints might be made, was held by those who should be supposed to know to the contrary.

In this city, I think, it is now fully recognized, by the electric light companies at least, that it pays to employ good jointers in underground work.

Several forms of joints are used on the electric light cables in subways, among them one known as the rubber joint. It is sometimes termed the half marine joint. This joint is made practically as follows: First the lead covering is removed for about 3 inches from the end of the conductor; about one inch of the insulation is then removed from the ends of the conductor; the ends of the conductor are then "sweated" together, a split copper sleeve generally being placed over the ends. When a T joint is to be made a T sleeve is used. This facilitates the making of the joint by dispensing with filing the ends of the conductor, and then wrapping them with small wire. No acid is used in the making of the joint. Resin is commonly used as slag. After the wire has been spliced the insulation is then scarfed for about three-quarters of an inch, when a layer of pure rubber strip is wrapped around the wire spirally, back and forth, about three times, and each time the rubber is brought further up the scarfed insulation. A few layers of white rubber strip is then wound above the pure rubber strip, and after that a layer or two of pink rubber strip. A layer of fibrous rubber tape is then put on over all. Between each layer of rubber strip a small quantity of rubber solution is put on to make the rubber adhesive and practically homogeneous. A lead sleeve is then placed over the joint and wiped on to the lead covering. This joint can be made in about 20 minutes, exclusive of time taken in wiping the lead sleeve. This joint is used altogether on the Bishop and the Safety cables; also

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occasionally on the Standard and Cobb cables. But as a rule the Cobb people make a special joint somewhat as follows: The ends of the conductors are spliced in the usual way, a hard rubber ferrule having first been placed over one end of the conductor and a brass ferrule over the other conductor above the insulation. A machine like a double vise is then placed over the lead covering of the cable and made fast thereto. A tightening device next draws the ends of the vulcanite together, taking up slack in the cable. The vulcanite sleeve or ferrule is then welded by heat to the vulcanite tube, after which the brass ferrule is drawn over the tube. A mould is then placed around the joint into which molten lead is poured, thus casting a solid lead sleeve. This is quickly cooled by the application to the mould of cold water. The mould is then removed and the joint is complete. This form of joint has been found satisfactory, I believe, and it is claimed that it can be made in much less time than a half marine joint.

The joint chiefly used on the Standard Underground Cable is made differently from either of the foregoing. After the conductor has been spliced as usual, and the lead covering has been cut back from the insulation, a few turns of tape is passed around the splice. A leaden sleeve is then put on over this and wiped firmly to the lead cover of the cable. When this has been done two or three small holes are punctured in the leaden sleeve through which a boiling insulating compound used in the manufacture of the cable is poured, filling up the sleeve completely; after which the holes are closed by solder. These joints have been found to give excellent service in this form of cable. The time taken in making this joint is about 30 minutes.

### LEAD COVERED CABLE.

The cables used in the electric light service in the New York subways are, as I have elsewhere stated, without exception, lead covered. In the case of fibrous insulation, this is essential to exclude moisture, but not in the case of the rubber cables, except as a protection against gas and acids, and to a certain extent, mechanical injury. The use of this lead covering is not required by the subway rules. In addition to being a protection against the attack of acids and gases, the lead covering is considered a safeguard against accidents to men working in the manholes among live wires. For, in the first place, if a defect should occur in the insulation in the manhole, the presence of a ground fur-

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nished by the lead covering would make the defect known at the regular test, which, if the defect were of a serious nature, would insure its being located and eliminated. Whereas, if the conductor were not lead covered there is a probability that a defect in the insulation might occur that would not be indicated by the test, but which might expose the conductor and render it possible for workmen in the manholes to make contact therewith. It would be quite possible for a workman to handle the lead covering of even a defective conductor without injury since the lead covering is grounded throughout the length of the subway.

It will hardly be credited by some people, but it is a fact that live electric light wires conveying alternating and continuous currents for arc and incandescent lights are handled and moved about in the manholes by means of the lead covering without the slightest indication that such wires are alive. Indeed, it is quite a common occurrence to start up such circuits immediately after a rubber joint has been made in order to save time and then to have the plumber adjust and wipe the sleeve on the lead cover while the circuit is in full operation.

Another fact is this, that in the subways no shocks whatever due to induced currents in the lead covering are felt by the workmen in handling the lead covered cables conveying the alternating current. It is quite conceivable that such shocks might be noticed, as I believe they are, where the cables are suspended from point to point and insulated. In that case any one handling the lead covering of the conductors would doubtless receive the accumulated induced charge.

It has been stated frequently that such induced currents, where the lead covering of the conductors is insulated, have been known to injure the lead covering and eventually to destroy the insulation.

So far as I have been able to ascertain, not in a single instance has such an action taken place in the subways.

As a matter of fact close personal observation and careful inquiry on all sides have failed to discover thus far any sign of deterioration in the condition of the material of the conduits, the lead covering of the insulation, or of the insulation of the cables in the subways, with the exception of the effect upon the lead covering of the telephone cable in the creosoted wood conduit referred to. I may add that even in the latter case, personal investigation and inquiry made of workmen have not confirmed

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the statement that the lead covering has been attacked. At all events there is no evidence of any such wholesale manufacture of white lead as has been reported from other places where lead covered cables have been placed in creosoted wooden boxes.

### INSULATION AND TESTS.

The requirements of the rules of the subway company, as regards insulation, are such that none but a first-class insulation can well be employed on the conductors assigned to high potential arc and incandescent circuits. These rules require an initial insulation resistance of 15 megohms per mile per 100 volts electro-motive force employed on the circuit, and a minimum of five megohms per mile per 100 volts. The initial test is made when the conductor is first laid in the subway, and prior to the turning on of the current. The minimum requirement is allowed after the circuit has been in use. This insulation requirement refers to the conductor proper in the subway, and does not include the lamps, aerial connections or converters. The rule does not apply to circuits of less than 100 volts E. M. F. In the case of alternating circuits, the uniform electromotive force employed in this city being 1,000 volts, the conductors to be employed in this service are required to show an initial insulation resistance of 150 megohms per mile, and a minimum insulation resistance afterwards of at least 50 megohms per mile.

The average E. M. F. of the arc light circuits in the subways is about 2,000 volts, but in some instances it runs up to 3,500 volts. In the latter case the initial insulation resistance required by the rules is 525 megohms per mile; minimum, 175 megohms per mile.

It was at first thought by many that it would be impossible to maintain even the minimum insulation resistance required by the rules, and this supposed impossibility was cited by some of the electric light companies as an instance of the impracticability of the proposition that they should utilize the subways. The representative of one such company very naively stated that it would certainly be impossible for his company to maintain this insulation if compelled to go into the subways, as the insulation his company used in its service was underwriters'. One of the experts of the same company, in his evidence, repeated the very common remark that one megohm, *if it could be maintained*, would be quite sufficient for practical purposes. I do not think

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this statement will be seriously contradicted, but the difficulty is to maintain the insulation resistance at one megohm in practice. Experience in the New York subways has shown that it is vastly easier to maintain the insulation resistance at 150, and even 500 megohms per mile than it has been in the past in other cities to maintain it at one megohm per mile. A gentlemen writing of the Chicago underground system, not quite two years ago, remarked: "It was found that although the insulation measurement of the lead covered cables in the conduit was very high, considerably above a megohm, a short circuit would form generally within 1,000 feet of the station between the two sides of the circuit."

The explanation for this short circuiting under such conditions would appear to be simple, namely, that if the insulation resistance of a conductor is but one megohm per mile, the covering being of the ordinary thickness, it is clear enough that it is decidedly inferior insulation; and if the normal insulation resistance of the conductor is very much higher than one megohm per mile, but the measurement nevertheless shows it to have an insulation resistance of but one megohm, it is or should be sufficient evidence that a fault has developed in the insulation which need surprise no one when it produces a short circuit or burn out.

As I was in no wise responsible for the promulgation of the subway rule which places the initial and minimum insulation resistance of the electric light conductors at the figures given, not having been connected with the company in any capacity at the time the rule was authorized, modesty need not restrain me from saying that experience of over a year has amply proven the wisdom of those requirements. For these requirements not only necessitated the use of an insulating material possessing high specific insulation, but also compelled the exercise of the greatest care in the details of placing the conductors in the conduits, in the making of joints, etc.

When it is stated that these conductors are jointed at every manhole, and in many instances at several places between manholes, the need of such carefulness in order to maintain a high insulation will be understood.

If, for example, the method of making joints that it is related was employed some years ago in Philadelphia—namely, to strip the ends of the lead covering for two or three inches and then to place three or four turns of tape around the ends of the conductor—had been followed in the New York subways, and had

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been permitted in the absence of the rules referred to, I think no doubt I would have had to report to-night a continued series of failures in the electric light service similar to those so often quoted as having happened in Philadelphia. I am confirmed in this belief by the fact that the first electric light conductors laid in the New York subways were found to possess an insulation resistance of but little over 100,000 ohms. This, notwithstanding that the insulation resistance of the conductors at the factory was over 2,000 megohms per mile. There were about 40 joints in these conductors. When these had been cut out and new ones made by an expert jointer the insulation resistance rose to over 1,500 megohms per mile, and a very recent test of the same circuit shows it to possess virtually the same insulation resistance.

Under the methods once in vogue in other cities in this country with regard to underground work, in which no tests for defects were made excepting for such as would be indicated by an ordinary magneto, the circuit I have referred to would have been put in operation without question, and there is, I think, not much doubt as to what the outcome would have been.

The high tension electric light conductors are tested weekly for insulation resistance. The tests are made by the direct deflection method, a Thomson reflecting galvanometer being used, and as a rule a 100-cell chloride of silver battery is employed as a testing battery. The tests are generally made from some room or basement adjacent to the terminals of the conductors in the subway, in order that the subway portion of the circuit may be tested exclusive of aerial portions.

At present the subways do not extend to the electric light stations, although in a very short time they will do so in the case of the Stanton Street United States Illuminating Company's station.

Where the conductors emerge from the subways they are run through subsidiary iron pipes up the side of a pole. From this pole the testing leading-in wires are run to the testing room.

The subway conductors are as a rule tested exclusive of arc lamps, converter and inside wiring, but frequently also the tests are made inclusive of arc lamps and converters. These latter tests are only accepted when the results fairly indicate that the decreased insulation resistance is due to the lamps or converters. In quite a number of cases the tests with converters included show an insulation resistance up to the requirements.

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Tests of circuits are not made inclusive of house wiring, because of the generally low results of trial test. Some such tests that I have made showed an insulation resistance of the house wiring of less than 1,000 ohms.

The following record of actual tests may be of interest:

Circuit A, Arc. Initial test 588 megohms per mile. Last test of same circuit 388 megohms. Present length of circuit 9.5 miles.

Circuit B, alternating. Initial test 141 megohms. Last test 1,250 megohms. Length 9.6 miles The first test was made when circuit was much shorter than at present, and doubtless, the terminals of conductor were exposed during that test.

Circuit D. Initial test, Jan. 6, 1889, 424 megohms per mile. Length of circuit, two miles. Subsequent test, Jan. 2, 1890, 484 megohms per mile.

Circuit E. Jan. 4, 1889. 1,750 megohms per mile. Same circuit, Jan. 4, 1890, 1,516 megohms per mile. Length, 1 mile.

Circuit F. July 7, 1889, 264 megohms per mile. Jan. 3, 1890, 343 megohms. Length, 6.6 miles.

The readings for these tests are generally taken after one or two minutes' electrification.

Tests with converters included in some cases show very fair insulations. One circuit with 34 converters included showed 11 megohms total insulation resistance. Another with 11 converters included gave a total insulation resistance of 159 megohms. It is not uncommon to get an insulation resistance of from two to five megohms with 30 and 40 converters in circuit. The foregoing tests did not include aerial portions of circuits. It should be said that the insulation of the converters and connections is being constantly improved, and, in my opinion, the time is not remote when the underground circuits will test up to the present requirements of the subway rules at all times with converters included.

As all of the conductors of the same company do not terminate at any one point, and the testing instruments have to be moved from place to place, the apparatus used is of a portable pattern. The entire outfit can in an emergency be carried by one person, and very readily by two persons.

Contrary to the expectations of some people, the actual making of these electrical tests has not been attended with any serious difficulty. The most troublesome factor has been that due to

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surface leakage at the battery or other parts of the testing equipment, during the very humid weather, which prevailed so continuously last summer and winter.

The time for making these tests is as far as possible chosen to suit the convenience of customers. The majority of the tests are now made in the early mornings. All circuits are tested once a week at least.

About 130 miles of the subway electric light conductors referred to are employed as carriers of alternate current for incandescent lighting. About 60 miles as carriers of arc light, and incandescent continuous currents. The circuits vary in length from one mile to eleven miles; the longest arc light circuit is 10 miles in length; the longest alternating circuit is 11 miles in length. In ten miles of alternating or arc circuit there are from 450 to 500 joints. The greatest number of converters on one subway circuit is 65. There are 14 arc light circuits and 25 alternating circuits in the subways.

Quite recently an alternating arc circuit has been installed in the subways which is intended to be the pioneer of numerous such circuits. I may say that it is ultimately intended to operate at least 125 arc lamps in such circuits.

### LIGHTNING ARRESTERS.

In the case of many of the electric light circuits that were first laid in the subways of New York city, lightning arresters were used at street lamps and at the terminals of the cable, and in a number of instances the same apparatus is still used. These "arresters" are those known as the Acheson cable protector, and are intended to protect the cable against disruptive discharges from any source. The principle upon which the device is intended to act is that the disruptive discharge, or what would be the disruptive discharge, will jump the air space between the points of the needles, thus relieving the cable from the strain. The utility of this device for the purpose intended has yet to be demonstrated in this city, inasmuch as the frequency of burn-outs in unprotected cables in the subways has been no greater than in those which are equipped with the protector; the percentage of burn-outs on cables in either case being, as I have before intimated, very low. It is as yet, I think, an open question whether the use of this or any equivalent device is necessary. There is no record of any of the cables in the New York subways having received injury from lightning during the past year.

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It is commonly supposed that the freedom from burn-outs which the successful electric light cables in the New York subways have enjoyed, as compared with the earlier experience of other cities, is due to an increased thickness of insulation around the conductor. This may be the correct explanation, but it is worthy of attention in connection with this subject that certain electrical condensers have for years been placed in positions where they are exposed to the full effect of lightning discharges on telegraph lines, without in a single instance having sustained injury therefrom. Similar instruments have also been placed across the poles of 1,000 volts alternating dynamo machines for days without perceptible harmful effect. Since it is difficult to imagine a better opportunity for a disruptive discharge to effect its escape to earth than that presented by the extremely thin tissue paper used in those condensers, the thought is suggested that if this paper can be so constructed as to act as a barrier to the passage of such charges there may be more to be considered in this matter of insulation than the mere question of thickness of the insulating material.

### ALLEGED DANGERS OF THE SUBWAYS.

The dangers to be apprehended from the existence of the electrical subways and from the placing of the high-tension electric light currents therein, according to those who are perhaps more or less inimical to that action, are varied. In general terms, they say that the dangers which menace the public and employees from the presence of wires overhead will be multiplied manifold when the wires are underground. But, when asked to specify those dangers, the reply is limited to the following, namely: first, that linemen will be killed by coming in contact with live wires in the manholes; second, that the "powerful" currents will leave the subways and enter buildings by way of water and gas-pipes, etc.; and, third, that accidents due to explosions of gas in the subways will be numerous.

As regards accidents to workmen in the manholes, due to contact with live wires, no one will say that such occurrences are impossible, but inasmuch as not a single accident of this kind has occurred in New York City, or so far as I can learn, elsewhere, in electrical subways, it is fair to assume that, with the exercise of proper supervision of the wires, this is not likely to prove a frequent source of accident. I was present at the inquest on one of the unfortunate linemen who was killed last year in New

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York City by contact with an overhead wire, when a witness who had just made the statement that he apprehended more accidents from the placing of wires underground than had occurred overhead, was asked if he was aware that there were at the time about 100 miles of electric light wire underground in New York City assigned to high tension circuits, and that not one accident had thus far occurred in the manholes; to which he replied that this state of things was explainable in his opinion by the fact that the electric light wires underground constituted but one-tenth of the electric wires of the city, and that when all the wires were underground the accidents in the subways would increase in the same proportion; which reply caused the foreman of the jury to remark that the public would probably not complain of an increase of accidents from nought to 10 times nought.

I have already suggested in another place that the fact of the wires being metallically covered may have conduced to the immunity from accidents which the workmen in the manholes have enjoyed. I may interpolate here that it is recognized that the efficiency of the manholes would in many instances be increased if they were larger, and wherever the surrounding condition of the street will permit, it is, I believe, contemplated to enlarge the manholes.

So far as the statement is concerned that danger is to be apprehended by the entrance of powerful currents into buildings by way of water and gas pipes, by contact of a grounded conductor in the subways, it would scarcely be worthy of notice before a body of electricians, but for the persistency with which it is said to be urged by men of prominence in the electrical profession. It is conceivable that if a conductor, within a building, should by accident come in contact with a well insulated gas pipe also within a building, one might receive a shock by contact with the gas pipe if in some manner he should complete the circuit, but in what manner, in the event of a ground in the subways, any dangerous current can be conveyed to the inside of a building by means of gas and water pipes which have the entire area of the city's foundation as a ground or return circuit is more difficult to understand.

But whatever may be the dangers, stated and unstated, so freely predicted as liable to occur with the wires underground, it may certainly be said that with the electric wires underground men will not be injured by falling off poles in the subways.

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Wires when in the subways during the prevalence of sleet storms, etc., will not fall upon people or horses in the street, nor be torn down by elevated railway trains, street cars, etc.

### GAS IN THE SUBWAYS.

In my opinion the presence of gas is the most serious defect of the electrical subways in cities; of course it is not an inherent defect in the subways, but it is nevertheless a very troublesome one, not only because of the danger of explosions therefrom, but also because of its ill effects upon workmen employed in the subways.

As previously remarked, the ducts used in the subways are not only joined together as nearly hermetically as possible, but, except in the case of distributing ducts they are laid in a solid body of cement from manhole to manhole. It is supposed that the gas obtains ingress to the manholes through the place where the iron manhole cover rests on the masonry of the manhole. But at whatever point the gas enters the subways, its unwelcome presence is acknowledged, and while it is self-evident to any one who will investigate the matter for himself, and is actually admitted by the gas companies that the gas emanates from the gas mains in the streets, nevertheless the subway engineers have been constantly at work devising means to remove the intruder.

To this end various methods for ventilating the subways have been suggested and tried, the most successful of which thus far has been the ventilation of the subways by the use of blowers stationed at intervals along the subways, and arrangements are now in progress to place fifteen such blowers in operation to cover the entire subway system.

As the ducts become filled with cables, however, the free passage of air through them is prevented, and in this way the utility of the blowers is diminished. In order to evade this difficulty a six-inch wrought-iron pipe has been laid above the subway ducts in the more recently constructed subways. This large iron pipe has openings at each manhole. The openings are graduated as to their extent as they recede from the source of the air pressure. The larger openings are at the points remote from the blower. It is intended by the use of these large pipes to furnish a counter-pressure in the subways somewhat exceeding any tendency of a pressure from the outside—rather than to produce a strong current of air through the ducts, and in this way to prevent the ingress of gas through any crevices that may exist in the subways.

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These air pipes are shown in the drawing, Fig. 5, to the right of the distributing ducts.

It has been frequently suggested that good results might follow a suction method of ventilation, but experience has shown that this would rather aggravate the evil, as it would draw into the subway all the accumulated gas in the streets besides inviting a large leakage from the gas mains.

The only beneficial effect to the subways of this resort to blowers to drive out the gas is that the air dries up the ducts and manholes within quite a distance of the blowers.

The cause of explosions in the subways has not in every case been definitely located. It is of course known that they are due primarily to the ignition of an accumulation of illuminating gas mixed with atmospheric air in the explosive proportions, but the difficulty has been to ascertain by what means the gas has been ignited. It is on record that these explosions have occurred in sections of the subways in which there were at the time no wires whatever. And in cases where there have been live wires in the vicinity of an explosion, tests made immediately after the event have shown that those wires were in practically perfect condition as regards insulation. There are but three instances on record in which a defect in an electric light cable has occurred simultaneously with an explosion in the subways, and in one of these cases the defect occurred so nearly incidentally with the explosion that while it is quite possible that the defect may have caused the explosion, it—the defect—may have been due to mechanical injury due to the explosion.

Among other theories it has been suggested that the gas may be ignited by currents induced in the lead covering of alternating current conductors. This might be the case if, as I have before suggested, the cables were supported from beam to beam, as on a bridge, on insulated stands, and if the lead coverings only approached each other at intervals; but where the lead coverings of the conductors are not only grounded throughout their lengths as in the subways, but are also joined metallically, in fact are practically one cable in the ducts, it seems unlikely that a quantity of induced electricity, sufficient to produce a spark, could be accumulated at any one point.

In the case of at least two explosions in New York City, the evidence showed that the gas in the subways had been ignited by a lighted lamp or match in the vicinity of some subsidiary duct

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connecting with the subways. In other instances by a match or lighted cigar thrown in a manhole. It is known that in Chicago an explosion was caused in the subways by a live coal from a passing fire-engine falling upon the cover of a manhole.

With but one or two exceptions the explosions have not injured the cables in the subways, which is probably due to the small and round surface which the cables present.

It has frequently been suggested that if solid ducts were employed instead of tubular ducts, these explosions would be avoided. While this would be, if correct, a strong argument in favor of solid conduits, that is, ducts in which the conductors are not removable, notwithstanding the generally admitted fact that such ducts are not practicable for subway work on a large scale, experience has demonstrated that explosions have occurred repeatedly in manholes and in small junction boxes of subway systems in which there were no hollow ducts.

I may add that, pending the installation of blowers in certain of the subways, men are employed day and night opening manholes to permit escape of gas.

I had intended to comment briefly on the comparative expense of maintenance and reliability of underground wires in cities as compared with overhead wires, but as my paper has far exceeded the limits which I had placed upon it, I shall leave that and other features in abeyance for the present. Perhaps something bearing on those points may be brought out in the discussion.

The following are some of the rules of the subways of New York City which have been promulgated as precautionary measures or as a result of actual experience.

No bare ends or bare portions of conductors, whether in or out of service, are permitted in the manholes. Every conductor in the manhole is treated as though it were operative.

No joints, except such as are protected by a metallic covering, are permitted in the manholes.

No exposed lights or fires are allowed in manholes.

All conductors in manholes are required to be arranged symmetrically around the walls and to be plainly tagged with the designating mark of circuit and the name of the owner. One of the pictures which I have, by the courtesy of Mr. Beckwith, the Chief Engineer of the Subway Company, been able to procure from his office, shows the cables passing through the manhole in rather a haphazard way. This would do where there are but one

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or two conductors in the conduits, but when the conductors multiply, an orderly arrangement of them is essential.

No switch boxes are allowed in the manholes. The reason for this is that, in the first place, a switch box for each company would take up too much of the limited room; and secondly, in the case of electric light circuits, it is feared that attempts to change live circuits might produce dangerous sparks in the manholes.

In conclusion, I think it may be said that the experience derived from the practical operation of the electrical subways of New York City has either made apparent or confirmed, among other things, the following:

That it is possible to successfully operate all classes of electric conductors underground in cities.

That at least for conductors conveying high-tension currents underground it is advisable to set the standard of insulation high.

That regular insulation tests of the conductors are very valuable.

That liberal thickness of insulation is desirable for high-tension currents.

That it is unadvisable to place underground new types of cable or insulation until they have been subjected to tests and conditions analogous to those to which they will be subjected underground.

That for electric light conductors — especially distributing mains—many conductors under one cover are not advisable owing chiefly to the difficulty in making joints in such cables.

That all sharp edges in ducts should be avoided.

That until the gas light companies are required, like the electric light companies, to maintain their mains in a fairly sound condition underground, a means of ventilating the subways should be provided simultaneously with the construction of the subways.

And lastly, that while other features may be accessories thereto, the employment of smooth, strong conduits, accessible ducts for distribution of the current, first class insulation, constant expert attention to details and thorough organization in every department, are essential to the production of a successful electrical underground system.

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DISCUSSION.

THE CHAIRMAN (Vice-President T. C. Martin):—I am sure we must feel extremely indebted to Mr. Maver for the very able and massive paper that he has presented to us this evening. It is a magnificent aggregation of data. And while we may not take the roseate and optimistic views that he does of the situation, we must feel that he has endeavored to present to us a truthful picture of the subways of New York City, as he knows them to-day. We shall now be very glad indeed to have a discussion of this paper; and I would like it to be as expeditious as possible, as the evening is already advanced.

MR. CHARLES CUTTRISS:—There is one question I would like to ask of Mr. Maver, that is, if any great drop in insulation has been noticed between summer and winter. As you know, we have in the Commercial Cable Company a straightaway line of some 12 miles under ground. The major part of that is gutta-percha. Four miles of it is the Standard lead-covered cable. The insulation of that circuit in January is generally the greatest and is about 1,000 megohms. In summer it drops to about 300. That is also observable in our sea cable between Wall street and Coney Island. That is a better line, and the drop there is from about 1,400 to 300. As most of the compounds used in the subways are either India-rubber or fibre, and as ours is gutta-percha, I would like to know if Mr. Maver has any data which bear upon that.

MR. MAVER:—As a matter of fact the results have shown a higher insulation of the cables since the approach of cold weather; and also in the case of new cables. But whether that is due to the cold weather or to improved methods of making the joints and more experienced workmanship, is a matter which I think another winter would have to disclose. I have, in speaking of the matter of an increased insulation noticeable at different times, thought that perhaps it was due to lower temperature, but I do not think there is as yet sufficient data to enable us to speak definitely on that point.

MR. CHAS. G. CURTIS:—I would like to ask Mr. Maver if he has any approximate estimate of what the subways in New York have cost so far per mile?

MR. MAVER:—I think about $3,000 per duct per mile. I am not positive; but I think I have heard that statement.

MR. CURTIS:—Can such ducts as they are now laying be built on the average for something like $3,000 per mile?

MR. MAVER:—I do not know positively. I did not speak by the book. I have heard that figure mentioned, I think. It may be four or five thousand.

THE CHAIRMAN:—I see Mr. Lauterbach here. Probably he can give us that information.

MR. EDWARD LAUTERBACH:—Of course, the cost depends very much on the number of ducts in a trench. To dig a trench and

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lay the concrete, and have only one or two ducts, will cost very much more per mile than it will with eleven or thirteen ducts. The precise average has not been ascertained, I think. But the figure that Mr. Maver mentioned may be looked upon as a minimum—the average cost per mile per duct would not be less than $3,000, and probably exceeds that amount.

Mr. Joseph Wetzler:—Mr. Maver in his opening remarks stated that many people thought the underground system in its ideal form should be a tunnel, which could in the first place contain all gas, water and other distributing pipes, and in addition the electric wires; and frequently Paris is held up as the ideal. Now, as a matter of fact, Paris having that ideal system of sewerage and about to go into electric lighting, does not propose to use it at all for the purpose of distribution; and I think his remarks in controverting that idea very apt. Indeed, in Paris to-day, instead of the sewers being full of wires, as many people suppose, there are probably not more than two electric light high-tension circuits. These were laid about ten years ago, and are still in operation, but none have been laid since. Where they are going into distribution to-day, they are actually using ducts which are built under the sidewalks. So that they have come also to see that the large sewer system is not what it appears to be as a system of distribution.

Mr. W. J. Hammer:—I would like to ask what proportion of electric light wires in the subways are at present live wires?

Mr. Maver:—Well, I presume, perhaps 95 or perhaps 99 per cent. I do not think there are over 10 miles of electric wires in the subways to-day that are not in active operation. If they are not in use it is simply because they have been recently laid, and are in process of being connected up.

Mr. Hammer:—I would like to ask also if these wires are connected with the overhead system? I presume, in the case of the Stanton street station, for example, that the wires run overhead some distance from the station before they go into the subways.

Mr. Maver:—Yes; that is true. They must necessarily go into the stations by overhead wires. The subways do not extend to the stations.

Mr. Georges d'Infreville:—I wish to supplement what Mr. Wetzler has said about the system used in Paris, which is perfectly correct. They do not use any insulation at all on their wire. In fact, they do not use wire. They use bars of copper, which rest on porcelain insulators. This system is, however, not used as yet to any great extent.

The Chairman:—There is one gentleman present whom I think we should hear from. I know that his native modesty keeps him quiet; and I can understand that there are other reasons why he is not particularly anxious to speak. But his work has been extensive, and so much greater than that of any

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one else in connection with the subways, that as one of our members I think he might give us an idea as to his opinion of the results that have been obtained. I refer to our highly esteemed and highly respected member, Dr. Wheeler. I think that Dr. Wheeler has had an ordeal that very few of us would care to go through. And I think that he has come out of it with credit to himself, and that is perhaps more than could be said of a great many who were subjected to such conditions as have prevailed in this city under the regime of the Board of Political Control.

Dr. Schuyler S. Wheeler:—Mr. Chairman, unfortunately I arrived here just as Mr. Maver was concluding, and I am not acquainted with the matter contained in his paper, and therefore, I hardly feel prepared to say anything on the subject. I feel that the matter of testing underground wires has been in the very best possible hands, and so I have not given as much attention to it as I might otherwise have done. My duties have been confined to the examination of overhead wires and perhaps their condemnation, and I do not know that I can add anything to the subject of wires underground. If there are any questions that anybody would like to ask me about overhead wires, I should be very glad to make an effort to answer them.

Mr. Wm. B. Halsey:—I would like to ask one question—has there been anything in the plans of the New York subway system looking toward the distribution of district circuits? I refer, of course, to the messenger telegraph.

Mr. Maver:—I presume they would be distributed in the same manner as the telephone and telegraph circuits. It is open to the district companies to avail themselves of these methods. That is, they would branch off from the manhole with their cables to the buildings where they have their district boxes.

Mr. Halsey:—The reason I ask the gentleman is, because, generally the district companies put in their boxes free of charge to the subscriber; and the consequence is that the general cost of anything of that kind would be a serious question. What I was getting at was whether the regulations of the subway system would allow such a thing, or whether they would have to put a special main in for each house?

Mr Maver:—I think I have stated in my remarks concerning the telephone and telegraph that the plan adopted was to run the cable in the subways to the manhole adjacent to the building or block of buildings where it is desired to made connection with the customers. Precisely the same plan, I should think, could very readily be followed by the district messenger companies.

In the first part of my paper, to which Mr. Wetzler has alluded, I assumed that a tunnel system would be the most satisfactory if the cost were not beyond all bounds; but it had occured to me that even if we had such a tunnel on one side or in the middle of a street, there would still remain to be furnished a distributing system. You would either have to pass from the tunnel in the

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middle or sides of the street or at street corners from manholes, as we do at present. But certainly, in addition to the tunnel, there would necessarily be for proper distribution, especially of electric light currents, a distributing system such as is at present employed above the regular or trunk line ducts. That, of course, would add greatly to the cost of the tunnel.

THE CHAIRMAN:—I see several gentlemen in the audience who are connected with arc lighting companies in this city. I should imagine that they would have some sentiments to express on such an occasion as this.

I have noticed that very often when we have a very important paper, one which we think will elicit the most valuable information, it sometimes fails signally of its purpose. For some reason or another we seem half afraid of it. We have before us such a paper this evening; but I would not like to have the meeting close without expressing my own belief that in these subway matters the companies which have been running their lines overhead to the present time have at least something to be said on their side; not so much by way of extenuation or excuse, as by way of explanation. Eight or ten years ago, to go no farther back, none of us expected that this electric work in New York City would be done for a long time to come by other than overhead wires. In fact, there was no desire expressed anywhere by anybody for anything but overhead wires. We had then simply the telegraph and allied services. If the overhead wire was not run to furnish some new service, the public grumbled until that wire was run. I think nobody can deny that. Then we had the telephone, and everybody who could afford it wanted telephonic service. The question of having these telephone wires run underground did not enter into the question at all. The only trouble was the price of the telephone service. Then we come down to the period of the electric lighting systems and their introduction into this city, a period of about a decade. Most of you who were present in the city at that time know that there was not the slightest call when the electric wires were first introduced into this city for putting them underground. Everybody said, let us have the electric light, it is a good thing, and the wires were strung overhead. On some thoroughfares, such as the Bowery, for example, they were plastered up so thick that everybody wondered whether the daylight would ever have any show again.

There was very little question as to insulation. The companies, I think, did the best they could. They were pioneers. They were not particularly well instructed in the matter. In fact, I do not think any of us were; and as pioneers, I think those early companies, some of whose work remains with us to this day, are at least entitled to our respect, even if we have to regret their mistakes. Just as long as our pioneers in America remain our glory and our promise for the future, I do not think that we

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have much occasion to find fault with those who are pioneers of electric lighting in this city, and therefore practically in this country. I recollect some years ago the Marquis of Salisbury ran wires through his garden, and in so doing killed his gardener. I am not aware, however, that the press of England has yet used that incident as the ground of a clamor for deposing him from his position as Prime Minister, or has alluded to it in any way as derogatory to his personal and private character. Had he, however, been connected with an electric lighting company in the city of New York, I dread to think of the things that would have been said about him; of what indictments he would have labored under. As Mr. Maver has told us this evening, the electric lighting companies, when the increase of the wires led to a public call for their being under ground, were offered the choice of any number of systems, and I know that in a great many cases throughout this country a large number of the electric lighting companies put large sums of money in subway work, all of which inside a year had to be written off to profit and loss. It need not be wondered at that companies with such interests at stake desired to go slowly and with fifty or a hundred systems presented to them, each the best and the others all the worst, it is not, I say, to be wondered at, that each company wished some one else would try the experiment first. We all know how the early subway work in connection with the electric lighting in this city failed. As I listened to Mr. Maver's description of that this evening, I was reminded of an incident told me by a fellow journalist a short time ago in connection with the yellow fever epidemic in the South. A young man there who was quite interested in Free Masonry, told his friends that when he died he wished to be buried in regalia. There were very few of his friends left by the progress of the epidemic, and the sad duties were left to an old negro who was told to go to this man's wardrobe and take his regalia and put it with the deceased in his coffin. It happened that this young man, while a Mason, was also a prominent personage in connection with the Mardi Gras festival, and had distinguished himself at the preceding festival by wearing a peculiarly brilliant and fantastic harlequin costume. You may, perhaps, imagine the consternation of his friends, two or three weeks afterward, when, looking over the young man's effects, they found the Masonic regalia—the harlequin costume was gone. Now, gentlemen, it may seem a false parallel, but the electric wires of this city deserved to be buried in a decent, respectable manner, instead of which they were sent before the great white throne of public opinion in what I may speak of as a harlequin costume. Within the last year, however, there has been an improvement, and I think none of us can gainsay the statement that Mr. Maver has made, which shows that at least the pioneer work of the subways is at the beginning of its end. We have gone through the overhead period for some eight or ten years, and now

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I think we may perhaps have a pioneer period of eight or ten years in the subway work. But we are getting there. I think all who are interested in the welfare of this business are interested in seeing the wires put underground, if they can be made to work successfully. Mr. Maver has shown us this evening how far the work can be accomplished, and I think it may be safely said that in the subway work of the future all those engaged in it will have the heartiest and best wishes of the American Institute of Electrical Engineers.

If there be no further business I would like to state that I have been asked by the Entertainment Committee of the New York Electric Club to mention that on Thursday evening Mr. Grosvenor P. Lowrey, a well-known lawyer of this city, will read a paper on the subject of patents and their relation to inventors. Any gentlemen who are interested in the subject the Entertainment Committee will be very glad to have as their guests.

I would also like to announce that our subject for the March meeting will in all probability be the Westinghouse tests at Johns Hopkins University. We all know the unimpeachable reputation of that university in such matters. But even if we did not, I think it would be sufficient to say that the paper will be brought before us by our Vice-President, Dr. Louis Duncan. That paper will probably be read in March. We have another matter on the programme for March, but it will probably be carried over until very late, or even into April; and that is a lecture at Columbia College by the kind invitation of its officers by Prof. Elihu Thomson on the phenomena of alternating currents, with experiments. I have no doubt that our President will give us a royal evening on that occasion.

Mr. James H. Seymour:—I am not a member of this organization. I do not know that I have a right to speak; but I do want to raise my voice in defense of the electric industry against the public howl which is brought forward in the daily papers. They think it is incumbent upon them to abuse every man in official position, and every one who is developing the electric industry. I have no remembrance of any industry ever meeting with the obstruction and with the abuse that the electric light business has met with in this city at the hands of the press. The press of New York has not been fair. Why it has not been I am unable to understand. I am aware that the citizens became annoyed with the numerous overhead wires, and wished that they might be buried; and from that howl, and through different commercial organizations they went for the wire question. The press has simply jumped upon the electrical industry and injured it to the amount of many millions of dollars in the United States, and has impeded its progress. I think those who are connected with it as an industry have a right to demand that we shall have fair play and the opportunity to build a subway and to take care of the wires overhead, and if by carlessness on the

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part of the companies people are killed, they are financially responsible, and let the responsibility rest where it belongs. Because there is an accident from the overhead wires, it is not just to require that the lights must be shut off as has been done in this city during the holiday season, where merchants have lost thousands of dollars in trade. At this point I would like to ask, as Doctor Wheeler invited questions about the overhead wires, why it is that insulation has improved so much in the last few days, from what it was when they were chopping the wires down so recklessly. Perhaps the gentleman can tell us about that. He, I presume, has come in for his share of abuse, and I am ready to defend him when it is required.

DR. WHEELER:—I have been out of town during the last week.

THE CHAIRMAN:—I think we ought to be extremely glad that Mr. Seymour is with us this evening, and has had the courage to speak on the action of the press in the manner in which he has. He said not a word but what was strictly true Our industry was treated in the manner that he describes, but the industry will survive, and I have sufficient respect and confidence in the great journals of New York City to know that they will be with us. Their own future forbids them being against us.

DR. WHEELER:—As the subject is rather serious, I think I had better make a more careful answer to the last question. As I understand the question, it is this, Why have the companies found that within the last week their wires are safe enough to light up, while before they were not safe enough? Well there has not been any difference in the safety of the wires, but from the time that they have been shut down, some months ago, the companies have been unwilling to take the risk of running, because they were ordered to discontinue the use of their wires until the electric adviser of the subway commission would certify that the wires were safe. Of course, I do not think anybody would undertake to go into the insurance business for all the wires in the city, and therefore the wires have not been declared safe. The companies were informed that the wires would all be examined as rapidly as possible, and that it would be necessary to examine them very carefully inch by inch; and that as soon as any wires were found that were safe the companies would be notified. The companies then, after talking the matter over, decided to go ahead and try to make some wires safe, and they came to the Board of Electrical Control and asked that some wires which they thought were pretty good should be examined. These wires were examined, and after going over them for a very small part of the whole distance a number of features about the wires were found which could be improved; that is, improved in an essential respect, and the companies were informed that as the resolution of the board required that the wires should be declared safe, it was not reasonable to expect that those wires would be declared safe as long as they were in a condition that could obviously be improved. The companies then said that they did

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not think that they could bring them into such a condition; that the changes required were not such that they could bring about, and they stopped work for awhile Within the last few days they have evidently made up their minds that they would take the responsibility of running their wires; and they have started up one of their stations, and lighted certain lamps. A good many of them are using their cables which they put in the subways, some of the cables being put in since the lines were cut down, but the companies are simply going ahead and taking the risk themselves, which I think they are quite sensible in doing. Before, they were not willing to take this risk, but now they are. The public clamor has subsided to a certain extent and they are simply using their wires.

MR. SEYMOUR:—Are the companies conducting their business without the Board of Electrical Control's permission?

DR. WHEELER:—Do you mean to say permission in respect to the Board declaring that the wires are safe?

MR. SEYMOUR:—No sir. Permission from the Board of Electrical Control to go on and do the lighting, as the public understand that they were shut down by order of the Board of Electrical Control. I want to know whether they have gone to work without the permission of the Board of Electrical Control or not.

DR. WHEELER:—I do not understand that the Board of Electrical Control has ever refused permission to any company to carry on the electrical business. The board simply passed a resolution at one time requiring the companies to cease the use of such wires as were not properly insulated, and until they could procure a certificate from the expert of the board that the wires were insulated and safe. They have not secured such a certificate, and they have made some effort which would prevent wires from passing an examination, and the matter lay in that condition sometime until within the last few days. Now they have decided that they will take the chance of whether the wires are safe or not—a position which is quite natural for them to take; and I should say quite sensible, because I do not think anybody could undertake to guarantee that all their wires are safe. They are simply operating them themselves, and if their wires are proven to be unsafe, as shown by any accident, they will simply be responsible for operating such wires. The board has not declared that any company shall not carry on its business—that is, as I understand it. I do not undertake the legal part of the business; but I do not think that there is any dispute about that.

MR. SEYMOUR:—Then I understand that the companies are going on and ignoring the Board of Electrical Control. If one company has that right they all have that right. If they are taking that position the Board of Electrical Control will practically have to take a back seat. If the companies now are stronger and more important and are simply defying the Board of Electrical Control, why we must know it.

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DR. WHEELER:—I do not think the companies have any intention of defying the Board of Electrical Control, and I do not think that the board has any idea of taking a back seat. The board passed that resolution evidently with the intention of really placing the responsibility where it should be. As there was a question at the time of who was accountable, and to make that perfectly clear, the board passed a resolution that no unsafe wire should be operated. If the companies choose to go on operating wires, and they are unsafe, then the companies are responsible, and if any harm results, they must answer for it.

MR. SEYMOUR:—They had that responsibility before.

DR. WHEELER:—Oh, yes. But there was a good deal of misunderstanding. There were a great many of the newspapers which seemed to think that the board was responsible. And the board tried to make its position perfectly clear by simply passing that resolution.

MR. SEYMOUR:—I think the fact has come out that the authority to destroy the property of electric companies does not exist in the Board of Electrical Control, or any other board; and they have probably taken a different view of that question. There are other ways of stopping business than by destroying property; and the fact that the city would be responsible for the destruction of property probably modified their views in the Board of Electrical Control. I like to get at the facts in these matters, and to defend our business.

MR. CURTIS:—It seems to me that one of the most important questions that has come up to-night has been the question of the comparative cost of tunnels, and what are called subways. Mr. Maver has instituted a comparison between the cost of tunnels for New York and the cost of subways, and the general conclusion from what I have heard to-night seems to me to be that tunnels would cost about $450,000 per mile, and subways would cost something like $3,000 per duct per mile. I cannot see why there should be such a great difference between the cost of subways and the cost of tunnels. Of course, there is a great difference—a tunnel requires a larger excavation, and it requires building the walls of very much heavier material, and it requires special removal and replacing of all the gas mains or electric wires which are there at present, also water mains and steam conduits. But as far as the cost of the tunnel itself is concerned, I do not see why that should be very much greater than the cost of the more expensive or more improved forms of subways. The advantage of tunnels in several respects is certainly very great. Service connections to the house can be made simply by boring through the walls of the tunnel right into the front cellar of the house. The water pipes and the gas pipes and anything that comes along in the nature of a new system—probably something will come along in a few years—can be introduced in the same way. When you consider the saving of cost that can be realized in the next five or

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ten years in the replacing of the old gas pipes and the old water pipes and the fixing of the sewers, and the constant shifting and adding to and testing of the electric light wires and electric wires of all kinds that would be necessary in order to keep such a system in working order, it seems to me, if it did cost something like $450,000 a mile, at the outset, it is not to be thrown out of consideration at all. If thirty years ago somebody had said, in answer to the proposition to connect New York and Brooklyn by a bridge, that such a bridge would cost fifteen millions of dollars, that would have settled it. But capital was forthcoming. And I do not see why, in the greatest city of this country, capital should not be forthcoming to put the subways or tunnels, or whatever they are, in condition to give the most desirable service possible. It seems to me it is largely a financial question. I do not myself see how any satisfaction can be got by the public or by private interests out of the present way of operating the wires by private corporations. It seems to me a very remarkable state of affairs that a private corporation should be allowed to have a monopoly of building subways for all kinds of electric wires, and that a Board of Electrical Control, or anybody for that matter, should have the authority to compel people to put them into those ducts. Because it amounts to an authority, they will not allow them to use them unless they put them underground. There are no other underground conduits so they have got to go there, and it is a very remarkable state of affairs that the company has got to put its wires underground in conduits, but cannot guarantee their working or take care of them properly. It appears to me that much the best plan is for the city to put the streets in such a condition that all kinds of service —gas, electricity, whatever it is —can be had to the best advantage, even though it may cost a great many millions; I think Mr. Maver said that in the principal streets to replace the present subways by tunnels would cost in the neighborhood of thirty millions. Well, if it cost thirty millions to give New York a system of water, gas, electric light, steam heat and sewerage, where there will be perfect access to the houses and where it will accommodate all these forms of supply, it would be a very desirable thing, and it would well repay such an investment. It, perhaps, costs several hundred thousand dollars a mile to pave a wide street in the best style, but a fine pavement is very important, and it is also most important that a city should be supplied with its light in the most convenient way. I think we ought to look far ahead in this matter and not consider whether the cost is three thousand dollars or one hundred thousand dollars per mile. Of course, it is impossible to judge what the consequences have been; and they do not furnish us with the means of arriving at any conclusion But, although it is a very old idea, nobody has advocated with any emphasis at all the best investment of sufficient capital to obtain the best means of supply for all these conveniences.

Adjourned.

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*A paper read before the American Institute of Electrical Engineers, New York, March 18, 1890, and discussion thereon. Vice-President Upton in the chair.*

# SOME TESTS ON THE EFFICIENCY OF ALTERNATING-CURRENT APPARATUS.

BY DR. LOUIS DUNCAN AND MR. W. F. C. HASSON.

Several papers have appeared lately on the efficiency of alternating current transformers, some of which have been of a more or less theoretical nature, while others have given the results of actual tests. I have never, however, seen any tests on alternating current dynamos, excepting the experiments made by Dr. Hopkinson and Professor Adams on a de Meritens machine used for lighthouse work. Even the converter tests have given such varying results that one can hardly be certain as to the real efficiency.

The introduction of the alternating system has been so rapid and is so rapidly increasing that people are apparently well enough pleased with the results not to bother about the smaller question of the reasons for them. But whatever the results may be, it is of value to know just where the losses in any system may come in, so that we may seek how to avoid them; if we are succeeding, it may enable us to increase the profits,—if we are losing, it may help us to avoid further loss.

The apparatus, the measurement of which is the main subject of this paper, consisted of a Westinghouse 750-light No. 1 dynamo, with a No. 2 exciter and an outfit of 40-light converters. This apparatus had been presented by the Westinghouse Electric Company to the Johns Hopkins University, and was tested a couple of months ago. The workmanship of the machines is excellent.

The plant consisted of a 75 h. p. Armington & Sims engine driving the dynamo and exciter through a Tatham transmission dynamometer. Engine, dynamometer and dynamos were firmly secured to heavy parallel timbers which served as a foundation. The converters were banked on a wooden framework at a distance

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of some thirty yards from the dynamo, and their primaries were permanently secured to the dynamo circuit, a switch in the latter serving to cut them off when desired. The ammeter belonging to the plant was put in this circuit and was read when efficiency measurements were being taken. The secondaries of the converters were taken to a switch-board and then to incandescent lamps mounted on racks.

*Power measurements.*—The Armington & Sims engine supplying the power worked regularly and satisfactorily and the governor could be adjusted to give the speed required at the dynamo. The Tatham dynamometer was the one used for power measurements at the Electrical Exhibition, held in Philadelphia, in 1884, where its accuracy was checked by making with it a de-

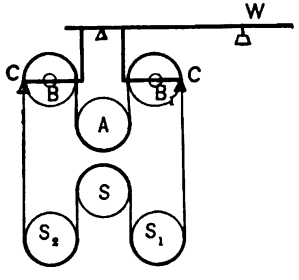


Fig. 1.

termination of the mechanical equivalent of heat. The result obtained in the latter measurement was 772.8 foot pounds per degree Fahr., and shows that the dynamometer is practically accurate. A description of the experiments and of the instrument may be found in the report of the test made to the Franklin Institute, but it will not be out of place to briefly describe the apparatus here.

An endless belt, as shown in Fig. 1, passes over the driven pulley, S, to the shaft of which the engine is belted, round the pulleys $S_2$ and B, to the driving pulley A, and back over $B_1$ and $S_1$ to S, again. The bearings of the pulleys B and $B_1$ are in cradles pivoted on knife edges, C, at their outer ends, and at the inner ends are connected by links at equal distances on the two sides of a knife edge which supports the scale beam W. The outer side of the belt passes through the line of the knife edges, C, and therefore has no effect on the scale beam, but the tensions of the inner parts of the belt act directly on the scale beam, and as they are on opposite sides of the fulcrum they act against one another. The beam is so graduated that this difference of tension is read

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off directly in pounds, and this quantity—the difference of tension of the belt on the two sides of A—multiplied by its circumference and speed, gives the horse-power delivered. A weight travels on the beam, w, and readings can be taken with great accuracy.

*Electrical measurements.*—The energy in the secondary circuit was measured by means of a Cardew voltmeter and a Thomson ampere balance. As it is not the custom to put a number of secondaries in parallel, each converter had its separate lamp circuit.

Before making an efficiency test, the potential difference in the primary was regulated,—there being a Cardew voltmeter in that circuit,—and a separate measurement of the potential difference and current in each secondary circuit was made. When the test was actually in progress the voltmeter and ampere balance were used in one of the circuits and the currents and P. D.'s in the others were calculated from the readings in this circuit together with the previous measurements. Both the voltmeter and ampere balance were accurately calibrated, the former being checked after each test, while the latter had its constant determined with both continuous and alternating currents. The P. D. at the terminals of a non-inductive german-silver resistance in circuit with the balance was observed, when a continuous current was flowing, and also with an alternating current of the same period as that employed in the test. The current in each case was calculated from the resistance and P. D., and the results gave no appreciable difference in the constant for continuous and alternating currents.

The following tables show at once the order in which the tests were carried out and the results:

HORSE-POWER ABSORBED AT VARYING E. M. F.'s.

| | E. M. F. | | H. P |
|---|---|---|---|
| | Dynamo | Exciter | |
| Horse-power for exciter, field not made..... | 0 | 0 | .34 |
| " " " field made ..... ..... | 0 | 110 | .75 |
| " " dynamo alone..... | 0 | | 2.73 |
| " " dynamo and exciter..... ..... | 0 | 0 | 3.04 |
| " " " " " ..... | 0 | 107 | 3.51 |
| " " " " " ..... ..... | 1376 | 124 | 12.5 |
| " " " " " ..... | 1168 | 104 | 10.1 |
| " " " " " ..... | 1099 | 105 | 9.60 |
| " " " " " ..... | 1040 | 105 | 9.0 |
| " " primaries of converters on..... | 1216 | 105 | 12.0 |
| " " " " " ..... | 1171 | 104 | 11.8 |
| " " " " " ..... | 1107 | 104 | 11.12 |
| " " " " " ..... | 1048 | 104 | 10.64 |

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TABLE OF EFFICIENCY AT VARYING LOADS

| Approximate load. | Exciter. | | Dynamo primary | | Converters | | Horse-power in lamp circuit. | Mechanical horse-power. | Loss, in horse-power. | Efficiency |
|---|---|---|---|---|---|---|---|---|---|---|
| | E. M. F. | Current. | E. M. F. | Current. | E. M. F. | Current. | | | | |
| ¼ | 105 | 9.4 | 1107 | 10. | 49 5 | 153.9 | 10.21 | 21.83 | 11.62 | 46.8% |
| ½ | 104 | 10.5 | 1107 | 18.9 | 49 6 | 338.4 | 22 50 | 34.4 | 11.90 | 65.4% |
| ¾ | 101 | 11 | 1113 | 28.6 | 5 .0 | 520.7 | 34.9 | 48.0 | 13.1 | 72.7% |
| Full | 113 | 11.5 | 1123 | 38.1 | 50.9 | 739.8 | 50.48 | 64.44 | 13.96 | 78.3% |

EFFICIENCY OF CONVERTERS.

*No.* 8. *40-light Converter.*

| No. of lamps. | Volts | Watts in secondary. | Loss in watts. | Loss in iron | Efficiency. |
|---|---|---|---|---|---|
| 40 | 50.0 | 2001 | 109 | ..... | 94.8 |
| 0 | 50.9 | 0 | 84 | 84 | ..... |

*No.* 4. *20-light Converter.*

| No. of Lamps | Volts. | Watts in secondary. | Loss in watts in secondary. | Loss in iron, watts. | Efficiency. |
|---|---|---|---|---|---|
| 20 | 48.8 | 952 | 106. | 95.2 | 90.0% |
| 15 | 52.2 | 817 | 114.8 | 108.9 | 87 6% |
| 10 | 50.3 | 506 | 101 7 | 99.2 | 83 3% |
| 5 | 51.44 | 264 | 109.4 | 108 7 | 70.7% |
| 0 | 52.3 | 0 | 110.5 | 110.5 | 0. % |

The efficiency of the converters was measured by placing them in a metal calorimeter, between the double walls of which water was allowed to flow. The temperatures of exit and entrance were observed, as well as the weight of water which passed through; at the same time the current and P. D. in the secondary circuit of the converter were measured. A separate observation gave the radiation, which was of course allowed for, although it was made as small as possible. A number of converters were experimented on but I give but two of them; a 40-lighter, such as was used in the tests, and a 20-light converter which was very carefully tested by two of my students, Messrs. Bliss and McKeen. In the latter case the observations were made at slightly different P. D.'s, and the results show that the loss in the iron varies as we would expect it to vary, that is, very nearly as the square of the voltage. The variation will not be exact, as the losses due to the reversal of magnetism do not vary quite as fast as the square of the induction.

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I would like here to call attention to the fact that in an excellent paper read before this Institute, Professor Ryan, of Cornell, found that the losses in the iron of a 10-light converter decreased greatly as the load increased. This was accounted for by the fact that there was a jar (evidenced by the singing of the converter) at the higher loads, due to the attractions of the secondary and primary coils. While it is true that the losses in the cores of very small converters are not exactly constant, yet they are nearly so, and a large part of the decrease found by Professor Ryan is due to the voltage being greater at the low than at the high loads.

Looking now at the figures given in the tables we are struck by two things; the very large amount of power absorbed in the core of the armature, and the very small loss in the converters

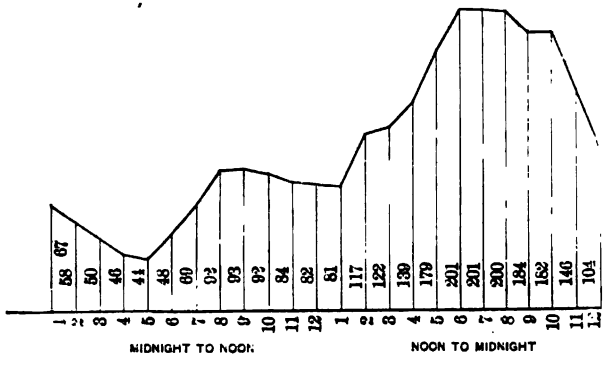


Fig. 2.

on open circuit. The dynamo losses due to reversals of magnetism and eddy currents, at the E. M. F. used in the test are no less than 6 h. p., while the energy due to reversal of magnetism and eddy currents in the 16 converters is only 1.6 h. p. Another rather striking thing is the almost constant ratio of primary and secondary currents over a considerable range. The maximum efficiency is about 78 per cent. It would seem that the losses could be divided into a constant part, and one varying with the current, but this is not true with the older style and smaller converters of the Westinghouse company.

Suppose we have a plant such as is described above, and use it for commercial lighting. Taking data from one of the local companies employed in supplying incandescent lights on this

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system we have, for two 2,500 light dynamos, the following outfit of converters:—

| Size of Converters. | Capacity. | Number in use. | Total Lamps. |
|---|---|---|---|
| No. 1. | 5 16 c. p. lamps. | 44 | 220 |
| No. 2. | 10 " " | 61 | 610 |
| No. 4. | 20 " " | 43 | 860 |
| No. 6. | 30 " " | 49 | 1,470 |
| No. 8. | 40 " " | 64 | 2,560 |
| Total lamp capacity..... | | | 5,720 |
| Number of lamps supplied.... ..... | | | ....4,557 |

I understand that the converters being added are of the larger sizes.

The efficiency of the 30-light converters does not differ greatly from that of the 40 lighters. The accompanying Fig. 2, is a load diagram of this plant, selected from a number of diagrams as giving a fair average curve. If in our 750-light plant we are to work our dynamo to its full capacity, then from the above ratio of converter capacity to lamps supplied we would need converters for about 900 lamps; say 23 forty-light converters.

If, as in our test plant, these converters are 40-lighters, or 30-lighters—for the efficiency of these two sizes is about the same—we would have a mean loss in our plant of, say, 10 h. p. in our dynamos ($9.6 + C^2 R$), and in the converters about 3 h. p. ($2.3 + C^2 R$); or all together about 13 h. p. From the above table we will have 750 lamps supplied, and taking the data from the load curve the average lamp load would correspond to about 20 h. p., and the efficiency of the plant for 24 hours would be $\frac{11}{18} = 61$ per cent., minus the percentage of loss on the lines. This, in a properly installed system, should not average two per cent., so that the final efficiency would be 59 per cent.

A continuous current dynamo supplying the same outfit of lamps, with a maximum loss in the mains of, say, 15 per cent., would have a greater average efficiency. But I wish to point out that the maximum efficiency of the two plants would be about the same, so that they would require the same capacity of station outfit, boilers, engines, dynamos, etc. When more than one dynamo is provided, the efficiency of the alternating plant is increased by using only one of them during the times of minimum supply, and always working as far as possible only a little below the maximum capacity of the machines.

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Let us consider these results in view of the present condition of incandescent light distribution in the United States. I take it that what may be called domestic electric lighting is largely a matter of the future—it is certainly not a matter of the present. The majority—the great majority—of the lights in use are in shops, saloons, theatres, offices, etc. Most of the lights wired are in use at one time or another during the 24 hours, and the proportion of energy supplied to the total capacity of the lamps connected is much greater than it would be in the case of house lighting, where, on the average, only a small fraction of the possible lamp-hours are actually in use. Under these circumstances the scheme of alternating current distribution is very different from what it will be when the attempt is made to supply an entire city with light, as they are attempting to supply London at the present time.

If the object of the lighting company is to supply the demand that exists at present, then a system employing a number of small converters is preferable. Such a system is flexible and can be installed with a minimum expense for the more or less scattered demand which is presented in even the most closely settled town. I take it that this is the great difference between the alternating and direct systems as at present installed in this country. The former skims over an extended district, taking advantage of its great flexibility to absorb any business which can be got; while the latter settles itself in a densely built centre, installs a larger plant than is primarily demanded, and works up a business within the limits of economical distribution. Therefore, it is hardly right to compare the present systems of direct and alternating supply, as the latter has not been reduced to a point where entire districts are to be supplied.

To show the disadvantage of the present system for domestic supply, suppose we have an ordinary house such as one of us would live in; it would be necessary to have a converter of at least 20 light capacity. The constant loss is, say, 100 watts; so, leaving out the $C^2 R$ loss, we would have a total loss in 24 hours, of $\frac{2400}{100}$, or about 3 h. p. hours, corresponding to, say, 45 lamp hours. Taking my own experience the actual number of lamp hours used is about 30 lamp hours during 24 hours, so the efficiency of the converter would be something like $\frac{30}{75} = 40$ per cent. It is evident that unless the losses in converters can be greatly

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decreased, a house-to-house distribution with a converter in each house would hardly pay.

It would seem, then, that when gas is to be displaced and serious competition with it is to be attempted a different system of distribution will be worked out. We must replace the numerous small converters with one large converter supplying a comparatively extended district, thus decreasing the total converter capacity since the law of average can be taken advantage of, and greatly increasing the efficiency. If an extended secondary network is employed, some of the converters may be disconnected from the mains at the time of minimum demand.

Let us inquire for a moment how the increase in the capacity of converters will modify the designs with which we are familiar. In the first place, if we increase the linear dimensions of any type, since the radiating surface only increases as the square while the volume increases as the cube of the dimension, then we cannot suffer the same loss per cubic centimeter of iron for the large as for the small sizes. We must decrease the intensity of magnetization or we must decrease the periodicity.

Let us take a typical case. Suppose we have a transformer and double all of its dimensions. If we employ the same induction we will need but one quarter the number of turns in the coils, and as the cross-section of the space occupied by the wire is four times as great, the area of the wire may be sixteen times as much. As the length is twice as great, the resistance in this case is one-eighth. But the losses in the iron are, roughly, eight times as great; this we cannot allow, since the radiating surface is but four times as great; hence we must diminish the induction. In fact we must so arrange things that the loss in the larger converter is only four times that in the smaller, in order to work at the same temperature. As at the low induction used the loss due to hysteresis varies nearly as the square of the induction, we may take it roughly that the large converter should have an induction of three-quarters of the smaller one. This will modify our figures. Instead of one-quarter the number of turns we will have one-third, and the resistance of the coils will be one-sixth instead of one eighth, as we can allow four times the loss that we suffered before, we can have, roughly, five times the output.

As a total result we have five times the output with four times the loss, or, as the $C^2 R$ effect is not important as compared with the other losses, we can have six times the output with the same

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fall of potential in the secondary. That is, the efficiency of the larger converters will be greater than the smaller ones of the same design and working at the same temperature, but the output per pound of metal will be less.

Suppose when we increase the size we decrease the number of reversals. Take a case, for instance, in which the dimensions are doubled while the reversals are halved, the maximum induction remaining the same. We could have half the turns in the coils, and as they occupy four times the space and are twice as long, the total resistance would be one quarter, and for the same heating effect we would have four times the output.

If we consider losses due to eddy currents these will be constant per cubic centimeter, provided the period and maximum induction are constant and the thickness of the plates is unchanged; otherwise they will vary as the square of the induction, with a constant frequency, or inversely as the square of the period with a constant maximum induction. This in practice would make the values of the output for the larger currents given above somewhat greater. What I wish to show, however, is that we are limited by heating considerations and considerations of fall of potential in our secondary in the output of large converters. If we consider the properties of the materials of which converters are made we would, I think, find it most economical to make converters that reach the temperature limit, except for the very smallest sizes.

Many of us have, I suppose, read Mr. James Swinburne's paper read before the British Association at Newcastle last year on the "Design of Converters," and have been struck by the fact that almost all of the converter dimensions given by him are impracticable, either on account of the disproportionate heating of the larger sizes, or the excessive fall of potential in the secondary. In increasing the size of dynamos we usually increase the output per pound weight, but there is the vital distinction between dynamos and converters, that losses occur through the entire mass of the latter, and as we increase the volume we increase the losses in the same proportion. In the dynamo, on the contrary, there are practically no losses in the heaviest part of the apparatus, *i. e.*, the field magnets. As a result, while we gain in efficiency in the larger sizes, yet we must decrease either our induction or the rate of reversal, and the output per pound is lessened.

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DISCUSSION.

THE CHAIRMAN (Vice-President Francis R. Upton):—Gentlemen, you have heard a paper that brings a new set of figures and measurements before the electrical world, and with such accuracy that they will probably stand as facts for certain constructions of apparatus. This paper, of course, brings up the broader questions—the questions of alternating and direct currents, and as far as their economical bearing is concerned, I think discussion directed to this point would be in order. We have Prof. Anthony with us to-night, and we should be pleased to hear from him.

PROF. ANTHONY:—I would prefer to wait and hear some of the others talk about this matter. Alternating currents I have never had anything to do with practically. There are people here to-night who have had to do with them and who know more about the results. I should be glad to hear from them.

MR. NIKOLA TESLA:—Dr. Duncan has brought forward some facts which have not been recognized before, for instance, the fact that the loss in the iron of the converter remains perfectly constant with varying loads. That has not heretofore been acknowledged or known so far as I have heard. But on the other hand, when we consider the action of the converter, I think it ought to be. In converters in which the primary and secondary are put in the closest possible relation, for instance, in the Westinghouse, the increase of the primary and secondary currents is in an almost constant ratio, and since the loss in the iron is due to something like a differential action of both currents, I think the loss of the iron ought to be constant within certain limits

With regard to the excessive loss in the dynamo machine—in the armature that Dr. Duncan has found, I think, that most of us know that this loss is not due to the fact that we must have that loss, but we must sacrifice a certain amount for the regulation of the machine. Now, the same machine that Dr. Duncan has tested any one of us could cause to give a greater output and with a loss in the armature of no more than one or two horsepower. But we must work with a highly saturated field, in order to obtain a constant potential on the converters. On the other hand, the comparison between the single circuit alternating current and the direct current machine is just, and the proportions I believe will be about as Dr. Duncan found them. That is, if we compare a single circuit alternating machine with a direct current machine we will find representing the output of the latter by a number—say by 100—that the alternate current machine with one circuit will give for the same speed and weight about 78, or perhaps less. But we must also consider that we are enabled with alternating current machines to work at a very much higher speed and the simplicity of the apparatus allows us to work with a very much higher electromotive force. On the other hand, if we operated an alternating machine with two circuits then the output of the machine will no longer be inferior

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to the direct current machine but it will equal it, if not be greater. I believe that Prof. Anthony some time ago told me that he also found that the loss in the armature by higher field saturation increased more rapidly than we would generally suppose. I have found also if you take a large generator and saturate the field very highly we may by only a few revolutions in a few minutes heat the armature so that the wires will burn out. I think the losses in the armature increase very greatly with the saturation of the field. Now, as regards the general results obtained by Dr. Duncan, I am firmly convinced of their correctness, of course, but I also firmly believe that Dr. Duncan has not had the best converter in hand. For I have myself made tests, and others have made tests, where the efficiency of such converters is shown to be much higher than is shown by Dr. Duncan. With the improvements we have made lately I believe that the new converters have now reached a much higher efficiency.

MR. H WARD LEONARD:—We had some theoretical discussion relative to comparative efficiency of the continuous and alternating currents at Chicago a couple of years ago. At that time we had very little beside theory to work on, especially as regards our knowledge of anything in the alternating field. But I was a little interested in looking over the figures, which at that time were arrived at theoretically, and comparing them with those which have been obtained The claim for the continuous current efficiency which was made there was based on a maximum loss of twenty volts on a three wire system, on each side, that is, fifteen per cent.; and the average load was considered as forty per cent. on that maximum. Therefore the average loss in the conductors was considered as six per cent. for twenty-four hours, that is, an average efficiency of ninety-four per cent. With the generators operated as they would be in such a system at full load by cutting off such generators as were not needed, assuming an efficiency for the conductor of ninety-four for the feeders, one per cent. average loss in the mains, one per cent. average in the service and inside wiring, brought the total efficiency of the continuous current system to a figure of 84.7. With the alternating current system the lowest efficiency that was assumed on account of the much higher figures that were claimed was 85 per cent. for the generator, 95 per cent. for the feeder, 90 per cent. for the converter, 99 per cent. for the service and inside wiring, which gave for the total efficiency 74 per cent. I was not fortunate enough to hear the actual efficiency which the present three-wire system showed; but I remember that the Professor gave the efficiency of the alternating as 61, instead of 74. I think that a point which is perhaps the most pertinent and which has been pretty well emphasized of late, is the fact that the average load of a system of lighting generally through a city is such a very small percentage of the connected devices. I know of one instance where the lighting has not yet reached the condition which it

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will later as regards supplying a much larger connected load than it has at present, and yet the average load for 24 hours is only about 12 per cent. of the connected load. This, of course, brings into very forcible action the efficiency of devices which are low in efficiency under conditions of light load. In the case that I have mentioned the maximum load is 30 per cent. of the connected devices, and the average load is 40 per cent. of that maximum.

DR. WHEELER:—Although I may not be able to add anything to the subject of converters, I might say something about the effect of alternating currents with parallel wires. I know of a case in this city where lines ran parallel for about three miles, and where the current pumped up and down continuously, causing the lights to beat just as if they were driven by a steam engine which did not have a heavy enough fly wheel. After a very extensive investigation, it was found that the pumping of the lights was due to the fact that alternations on two circuits were nearly but not quite synchronous. When one set of waves caught up with the set of waves on the next wire while passing them they first drove those waves ahead and then drove them back. This caused the energy of one circuit to first pile up the energy in the other circuit, and then force it down, and thus cause a pumping effect on the lights. That was overcome entirely by placing the wires in pairs properly, that is to say, the two legs of each circuit had not been arranged side by side. One or two of the circuits had been misplaced. But by bringing those together, so that the negative side or "leg" of one circuit was right alongside of the other "leg" of its own circuit and not mixed up with the wires of any other circuit, the induction was completely neutralized, and that left the lights perfectly steady. This has nothing to do with converters, but is about the only thing that I can contribute to the subject. It was quite important. The lights pumped very badly. The company was very much troubled to know what the cause was. I had been formerly driving Edison dynamos with high speed engines and I laughed at the people who were running the lights, and assumed that their fly-wheel was not heavy enough. They suggested that I could go and try the fly-wheel. I made them buy a very expensive speed indicator and put it on, and about as soon as they got it running I made up my mind that the inertia of the indicator mechanism would be too great to allow it to respond quickly enough, that is to say, if the steam engine made about 74 revolutions a minute, as it did, and if its speed varied enough to show a flickering in the light, which would be about two per cent. variation in the middle of each stroke of the engine, it would not be easy to get a speed indicator needle which would show such brief, rapid and small variations as two per cent. variation on every stroke, that is, in less than one second for each. I then tried figuring out the weight of the fly-wheel and how much its speed ought to increase

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or decrease between the strokes. Assuming the fly-wheel weighed 30 tons and had a diameter of 30 feet, and 500 horse-power was being drawn off by the belt continuously and was being put into the fly-wheel twice in every stroke by a brief impulse of the pitman with no source of power in the intervals, how much would the wheel slow down in the seventy-fourth of a second? In other words, how much would 500 horse-power slow down a 30 ton fly-wheel of 30 feet in diameter in the seventy-fourth of a second. About the time I made up my mind that this would be a long matter to figure out, I decided to try the plan of substitution, that is, to change all the elements of the system one after the other, until I found to which element—for example, the dynamo, the lines or the engine—the trouble was due. We therefore tried driving the different dynamos by different engines and connecting different lines on to different dynamos. We then found that the trouble went with a particular wire. That surprised me. I had gone so far in the matter then that I decided I was in honor bound to see it through. I went out and counted the number of pulsations in the lights and found that they were about eighty to the minute. I had inspections made and found there were only two parts of the city where the lights pumped in this way. I then immediately compared the pulsations of the other sets of lights and found they were 80 to the minute; the same as the first group. I then concluded there must be some reaction between the lines supplying the two districts. Following the wires out I found that the two sets of wires that supplied these two groups of light were placed in a position where they could act inductively on each other, while the others were so placed that they could neutralize their own effects, and I suggested that one set of wires be changed about. This was done and there was no more pumping. It was clearly due to one set of alternations "beating" with the set on the other wire.

MR. TESLA:—A point mentioned by Dr. Duncan was, how the construction of the converters would be modified when their size is increased. I had hoped that Dr. Duncan, whose work in that line has always been so valuable, would give us some points on that. It is evident to every one that it is impracticable to increase the size of the converter in the same proportion as its capacity is increased; because, as we operate the converter at a constant number of periods, we would render a long magnetic circuit transformer very inefficient. A plan was proposed by me a year or so ago to introduce this system in the construction of converters to have the same length of magnetic circuit, no matter whether the converter is large or small. I believe that this would be the proper way of constructing all converters on one system, and I believe that the present method of constructing converters is not right, for every different capacity of converter has a different length of magnetic circuit, and we know well that if one converter is adapted to, say 16,000 reversals,

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another one with a different length of magnetic circuit is not adapted to the same number of reversals. We started a year ago, I think, to make all converters of the same length of magnetic circuit, so as to render them equally adaptable for the same number of alternations, no matter what their capacity is, and in such case, if we want, for instance, a converter that has ten times the capacity of a small twenty light converter, we will practically put in one converter so many multiple circuits as are required to get the capacity desired. We will allow a somewhat greater capacity to maintain the converters all at the same temperature.

I think that this plan should be followed. In general, I may say that the results obtained by Dr. Duncan refer to an apparatus a considerable time in use, but the advances that have been made in that line the last year only, are so enormous that we would not recognize this plan at all. For instance, I believe that the converters at present can be made to have less than half the leakage that they had previously In other words, it means practically you can run a converter with a double load—the machines are increased very nearly to double their capacity; and when we consider the short interval in which this has been accomplished, we may fairly assume that in a few years from now there will be little difference between the alternating and direct current, even on short distances. We will wait for that development in the meanwhile.

Dr Duncan:—In respect to the construction of converters, of course, in increasing the dimensions in the same proportion, I was not following out the proper design for every given converter. Every converter of a given design has its own proper dimensions, and all dimensions do not increase in the same ratio. But I think that Mr. Tesla's idea of keeping the same length of the magnetic circuit is hardly proper. I have worked out for my own amusement the design of a number of converters. For a converter of given capacity, there is a definite period which with the best proportions of iron and copper, corresponds with the maximum efficiency of the converter, but if you simply increase the cross section of the iron without increasing the length of the circuit you keep the same cross section of copper, which is not a good practice. You have to change both the copper and iron, and I did not think it would be very interesting to design a large number of converters for any given output. As for the efficiency of this plant which was tested, the plant was sent on, I think, in November, and was supposed to be the latest plant which was produced by the Westinghouse company. I have since heard that the efficiency of converters has been greatly increased. The losses in the converters could undoubtedly be greatly decreased, especially for larger sizes. As to the relative efficiency of the two plants, it must be remembered that I have simply taken a seven hundred and fifty light plant, and one dynamo is supposed to be always connected with the circuit. In a station of

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ordinary capacity, that is of more than twice 750 lamps, we would certainly have the advantage of having at least two dynamos, one of which could be disconnected when the load had reached its minimum and the efficiency would therefore be greatly increased; and also in comparing efficiency of alternating and continuous plants, we must remember that the business that is catered to by these two systems is very different; that the load diagram of the alternating plant is very different from the load diagram of the continuous current plant. An alternating plant takes up the cream of the business, so to speak. It takes up business in which they get the maximum output for a given number of lamps wired, and in that way we must not calculate the efficiency of the alternating and continuous current plants at the same average load in comparing them. If so, we are favoring the continuous plant very much. With the alternating current plant it is simply a commercial question. If you can put into a continuous current station an alternating dynamo which will get business that will pay you, it is undoubtedly proper to put that dynamo in. In the same way if you have an alternating plant and it is so situated that you can run part of the service more economically with a continuous current, then put in a continuous current dynamo. But as the business stands at present a combination of the two plants is undoubtedly the most efficient in many cases.

Mr. O. T. Crosby:—I should like to ask if the advances reported are in the direction of increasing the efficiency of the converter at all loads, or only at some normal loads?

Mr. Tesla:—I said before, that the leakage was reduced to one-half, and I thought it was clear enough that that applied as well to the working of the converters on the full load as on the small load. When I speak of leakage I mean no load at all. But Dr. Duncan said just now—I thought he misunderstood me in regard to the construction of these converters—I proposed not to keep the length the same and vary the section simply, but to vary the section of the copper, at the same time varying the section of the iron. We have plates, for instance which contain so many multiple circuits. These plates are so made that the coils can be just as well put in as one single circuit transformer, a form of construction invented by Mr. Albert Schmidt of the Westinghouse company, and in this way we have practically a number of independent transformers, and the only diminution of the capacity of such transformers is that we have got a somewhat smaller surface Then we may allow a little higher capacity for that diminished surface. That is all. I think that point is very clear; and there is no doubt at all that this contruction should be followed.

Mr. Fred'k Darlington:—There is one thing which I think merits attention in the discussion of this question, that is that one system uses the 50 volt lamp, and the other system is forced to use a 100 or 110 volt lamp, and that by the same skill of con-

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struction of lamps and the same advance in the art of manufacturing lamps, the 50 volt lamps represent about twenty per cent. more efficiency than the 100 volt lamps. That is found in practice. For instance the 100 volt lamps which are being supplied now by one of the large commercial manufacturers of lamps are six-tenths, or a fraction over six-tenths of an ampere and 100 volts; while the manufacturers of 50 volt lamps make a 50 watt lamp and get 50 volts out of the lamp and a better service for the time. I can tell of results that have been obtained by the Westinghouse Electric Company recently in the improvement of converters. They were manufacturing for a considerable time a converter that gave a leak of twelve one-hundredths on every 40 light converter and, recently, since certain analyses have been made of the iron and the quality of the iron has been improved and the method of annealing the iron has been improved, they have reduced that leakage from twelve to seven hundredths of an ampere, and the point that Dr. Duncan mentions that in putting in the alternating system they are able to take out the lamps in the service—certain circuits one gentleman said only about twelve per cent. of the total number of lamps burning on an average—I can state what is given here in New York in the service of the United states Illuminating Company. They are getting out of the total number of lamps wired on a circuit five and eight-tenths hours per lamp, which is about 23 per cent. All those points, I think, if taken into account will make the efficiency of the alternating current come much higher than would appear at first thought.

MR. TESLA:—Another point of great importance is the fact that in the alternating system you have got an apparatus of almost ideal simplicity. If the armature burns out it is a matter of a few hours' work; and the repairs cost very little. If any part of the apparatus gives out it is easily replaced without trouble. With a direct current system, I think on the average out of 100 armatures, if you take them on a year's run, there will be about fifty that will have some trouble or other. The commutator will wear out in a few years, even with the best attention. I speak, of course, of the average.

THE CHAIRMAN:—I think we are letting the subject wander a little from the efficiency of the alternating current apparatus. I think we had better keep to that subject.

MR. TESLA:—I beg to remark on this that the title of the paper of Dr. Duncan was the tests on the efficiency of alternating current apparatus, and I never thought that the other subject would be mentioned. But Dr. Duncan's paper assumed the shape of a comparison of the efficiency and merits of the systems, and if I have wandered a little too far, I beg your pardon; it was not my fault, as the talk drifted in that direction.

LIEUTENANT JOHN MILLIS:—I believe in all the alternating systems that are now in practical operation in this country the

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rapidity of alternations, that is, the number per second, is practically the same. I would like to inquire what are the considerations which have determined this rate of alternations, whether they are mechanical or electrical, and if so, if Dr. Duncan can briefly explain to us what they are, also what the effect would be if the rapidity of alternations were varied. He touched lightly upon the theory of the effect that would be produced in the output or efficiency of the converter if the rapidity of alternations varied. I would like to ask if this theory has been confirmed by him, or to his knowledge by any one by practical experiment, and what the result of the experiment is.

DR. DUNCAN:—The rate of alternation is determined very greatly by the size of the unit in which the distribution is made. For large units a low rate is commonly employed. You will find in most of the continental and English systems that the rate of alternations has been decreased as the size of the converter has been increased. For a large converter a comparatively low rate should be used, and as in this country small converters have generally been employed, the rate is very much greater than where the converter has been large.

MR. TOWNSEND WOLCOTT:—Dr. Duncan referred to Prof. Ryan's paper and his idea in regard to diminishing the energy absorbed by hysteresis by vibrating the iron. Mr. Kennelly seemed to have the same idea as Prof. Ryan that you could get rid of the waste of energy very largely. The diagram of the hysteresis for one period as drawn by several experiments is as shown in Fig. 11 of Prof. Ryan's paper, one point at the bottom and the other at the top. Now, if you can come back by the same path as you go, of course, the energy is zero. But Mr. Swinburne divides the hysteresis into two kinds. He speaks of viscous hysteresis and ordinary hysteresis. Previous to the presentation of Prof. Ryan's paper I had the impression that the whole hysteresis worked in the manner which Mr. Swinburne calls viscous hysteresis; that is, like friction, it would resist in both directions. Mr. Swinburne's idea seems to be that the energy absorbed depends to a great extent upon the difference of phase between the magnetism in the iron and the magnetizing force of the current.

DR. MICHAEL I. PUPIN:—I would like to ask Dr. Duncan whether he knows of any experiments that have been made lately for the purpose of finding out how much of the lost energy is due to eddy currents and how much to magnetic hysteresis. As far as I am aware, there has been no experimental work of that kind done, and that has been spoken of as a work which it is very desirable to do—to determine the ratios between the two. I think that would also give us a means of testing whether work lost on account of magnetic hysteresis is the same for every period — whether they obtain the same current, as shown in the diagram referred to by Mr. Wolcott.

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DR. DUNCAN:—I am not prepared to give any figure on that point because I am experimenting on it at the present time. I am working now to weed out the eddy currents, and to determine the effect of hysteresis for different periods of reversal. There is no data at present to tell whether the loss on the iron is due to viscous or static hysteresis. If we go through the change in magnetic force at a very low speed then losses due to time hysteresis will not come in at all. If we go at a very high speed it will not come in at all. If we go at the present speed it will come in. As I say, at present my work is in trying to weed out the eddy currents. But I have not reached any results; and it is not a part of the paper. It is a very important question, though.

MR. LEONARD:—I take the liberty of speaking for a second on the question of a five hour load. I had been brought to select in the instance I noted the most exceptional one I knew of as being the future condition of supplying loss of all kinds. In New York City, which, of course, is the most exceptional in the other direction, the Edison station here has instead of five, nearer eight hours average load which, however, may be somewhat due to the advantages derived from the sale of motive power.

MR. JUSTUS B. ENTZ:—I would like to inquire if the losses due to eddy currents and hysteresis could not be determined by different thicknesses of discs. By taking two readings and separating them, I think it could be determined—the loss due to the eddy currents, of course, varying as the electromotive force. If the thickness of the disc is doubled the potential is doubled, while the resistance making a watt loss in each disc, varies as the cube, and if the disc in the converter were double in thickness and the same amount of iron, and the loss measured in the two cases, I should think they could be separated.

MR. TESLA:—I should think, gentlemen, that if hysteresis is a distinct element in the loss of the converter it can be only so because it is intimately connected with the generation of the currents in the iron. We cannot go beyond a certain thickness of the iron—say number 38 or 40, which may be yet thick enough to give rise to the currents in the iron. But the results that Dr. Duncan has to-day brought out strengthened me in the idea which I always had, that ultimately the whole loss in the iron resolves itself into the loss due to the currents. The facts he finds show that the principal loss is due to the eddy currents. The loss in the iron is constant at all loads; on the other hand, he finds that the loss is proportioned to the square of the electromotive force, which would be precisely the case if the loss in the iron were due to eddy currents. I think that is an argument for this view.

MR. CROSBY:—It seems to me in that case that we want to know something of the subdivision of the iron, because by a very slight subdivision we might get the eddy current so predominating over the other effects that it might be when the subdivision were finished that they would appear as perhaps the

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larger effects. I should like to ask Dr. Duncan what the cubic contents of the iron masses were whose total loss is given in the paper? It may have been stated, but I did not hear it.

DR. DUNCAN:—I think it is possibly in the paper. If not, it is somewhere else, and I would be very glad to give it to Mr. Crosby. As to distinguishing between the hysteresis and eddy currents with different thicknesses of plate, unfortunately Ewing has found that as far as this time hysteresis is concerned, it depends on the thickness of the plate independent of the eddy current. So, it would be impossible to distinguish in that way.

Adjourned.

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OF

# CURRENT ELECTRICAL LITERATURE,

&c. (September,, 1889.)

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**Conventions of the Military Telegraph Corps and Old-Time Telegraphers.** *West. Elecn.*, Sept. 28, p. 173; *N. Y. Elec. Rev.*, Sept. 21, p. 5; *Elec. World*, Sep. 28, p. 218.

**Telegraphy Regarded from a Financial Point of View—High Speed and Low Speed.** *N. Y. Elec. Rev.*, Sept. 7, p. 7.

**The New Telemeter System.** (Ill.) *Elec. World*, Sept. 21, p. 199.

## SUBMARINE CABLES, ETC.

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**Proposed Pacific Cables.** *West. Elecn.*, Sept. 7, p. 137.

## SIGNALS, ETC.

**Electric Signals at Railroad Crossings.** *N. Y. Elec. Rev.*, Sept. 14, p. 2.

**Improvements in Railway Signalling.** H. J. Peddie. (Note.) *Lond. Elecn.*, Sept. 13, p. 467.

**A Railway Signal Device.** (Note.) *Lond. Elecn.*, Sept. 27, p 517.

**Electric Signalling from Ships.** *Science*, Sept. 20, p. 194.

## TELEPHONE.

**Telephony.** M. de la Touanne (Int. Elec. Conf., Paris, Aug., 1889). *Elec. World*, Sept. 14, p. 188.

**Ocular Demonstration of Telephone Vibrations.** *Elec. World*, Sept. 14, p. 184.

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**The Wheeless Telegraphophone.** (Ill.) *Elec. World*, Sept. 14, p. 184; *Science*, Sept. 20, p. 194; *Lond. Elec. Rev.*, Sept. 27, p. 357.

**Switchboards and Long Distance Lines on Grounded Circuits.** Flemon Drake, Nat Tel. Con. *West. Elecn.*, Sept., 21, p. 157; *N. Y. Elec. Rev.*, Sept. 21, p. 3; *Md. Lt. & Ht.*, Sept. 19, p. 339; *Elec. World*, Sept. 21, p 207.

**Single Wire Multiple Board.** G. J. Davison, Nat. Tel. Con. *West. Elecn*, Sept. 21, p 159.

**Telephone Switchboard Improvements.** *West. Elecn.*, Sept. 14, p 144.

**The Beach-Cook Switchboard Transfer System.** (Ill.) *Elec. World*, Sept. 14, p. 187; *N. Y. Elec. Rev.*, Sept. 14, p 6.

**The Telephone Convention.** *West Elecn.* Sept. 7, p. 135; Sept. 14, p. 143; Sept. 21, p. 153; *Md. Lt. & Ht.*, Sept. 19, p. 334; *N. Y. Elec. Rev.*, Sept. 14, p. 1; Sept. 21, p. 1; *Elec. World*, Sept. 21, p. 205.

**Telephone Salutations.** R. M. Bailey, Nat. Tel. Con. *West. Elecn.*, Sept 21, p. 157; *N. Y. Elec Rev.*, Sept. 21, p. 11; *Md. Lt. & Ht.*, Sept. 19, p. 340; *Elec. World*, Sept. 21, p. 207.

**Remarks on the Telephone Exhibit at Paris.** W. D. Sargent, Nat. Tel. Con. *West. Elecn.*, Sept. 21, p. 159; *N. Y. Elec. Rev.*, Sept. 21, p. 2; *Md. Lt. & Ht.*, Sept. 19, p. 334; *Elec. World*, Sept. 21, p. 208.

**A New Era in Telephony.** A. S. Hibbard, J. J. Carty and F. A. Pickernell. *West. Elecn.*, Sept. 21, p. 154; Nat. Tel. Con.

**Telephone—Undergrounding.** *N. Y. Elec. Rev.*, Sept. 7, p. 5.

**Underground Construction Work of the New England Telephone and Telegraph Company.** (Ill.) *Elec. World*, Sept. 14, p. 179.

**Chicago Telephone Subway System.** (Ill.) *West. Elecn.*, Sept. 14, p. 142.

**Telephonic Communication between London and Paris.** W. H. Preece, Brit. Assn. *Lond. Elec. Rev.*, Sept. 20, p. 319.

**Long Distance Telephony in Northern Europe.** *Lond. Elec. Rev.*, Sept. 20, p. 313.

**The Taking Over of the French Telephones by the State.** Le Soleil. *Lond. Elec. Rev.*, Sept. 6, p. 266; *N. Y. Elec. Rev.*, Sept. 28, p. 5.

**The Telephone in the West of England and South Wales.** *Lond. Elec. Engr.*, Sept. 6, p. 188.

**Telephonic Communication between London and Paris.** W. H. Preece, Brit. Assn. *Lond. Elec. Engr.*, Sept. 27, p. 249; *Lond. Elecn.*, Sept. 20, p. 505.

**Dynamo Alternating Current Interference With Telephone System in New Orleans.** E. H. McFall, Nat. Tel. Con. *West. Elecn.*, Sept. 21, p. 157; *N. Y. Elec. Rev.*, Sept. 21, p. 11; *Elec. World*, Sept. 21, p 208.

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## ELECTRIC LIGHT.

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**Lighting the Washington Navy Yard.** *Elec. World*, Sept. 14, p. 183.

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**Royal Electric Company's System.** (Ill.) *West. Elecn.*, Sept. 28, p. 166.

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**St. Louis City Electric Lighting.** *West. Elecn.*, Sept. 7, p. 130; Sept. 17, p. 144.

**The New Central Station of the Narragansett Electric Lighting Co., Providence, R. I.** Nat. Elec. Lt Assn., J. T. Henthorne and C. R. Remington. *N. Y. Elec. Engr*, Sept., p. 404.

**The New Station of the Edison Illuminating Company of Brooklyn.** *N. Y. Elec. Rev.*, Sept. 14, p. 2; *Elec. World*, Sept. 14, p. 188.

**The "Teutonic's" Electric Plant.** *Elec. World* Sept. 14 p. 178.

**Electric Lighting in Asia.** *Lond. Elec. Rev.*, Sept. 13, p. 286.

**Shipyard Lighting in Belfast.** *Lond. Elec. Rev.*, Sept. 6, p. 256.

**The Electric Lighting of River Steamers.** (Ed.) *Lond. Elec. Rev.*, Sept. 6, p. 253; *Lond. Elec. Engr.*, Sept. 6, p. 198.

**The Electric Lighting of London.** *Daily News. Lond. Elec. Engr.*, Sept. 27, p. 254.

**The Electric Lighting of the Savoy Hotel.** *Lond. Elec. Rev.*, Sept. 27, p. 364; *Lond. Elec. Engr.*, Sept. 27, p. 251.

**Improvement in Electric Light Shades.** (Ill.) A. A. McCreary. *N. Y. Elec. Rev.*, Sept. 21, p. 11.

**Bryant Switch.** (Ill.) *West. Elecn.*, Sept. 7, p. 133.

**The Brush Electric Company's Prosperity.** *Md. Lt. & Ht.*, Sept. 12, p. 311.

**Electric Lighting and Insurance.** C. C. Haskins. *West. Elecn.*, Sept. 28, p. 167.

**The Measure of Illumination.** W. H. Preece. *Lond. Elecn.*, Sept. 13, p. 478.

**The Perfect Arc Central Station.** Nat. Elec. Lt. Assn. M. D. Law. *N. Y. Elec. Engr.*, Sept., p. 401.

**Economical Size of Line Wire for Constant Current Circuits.** B. Rhodes, Nat. Elec. Lt. Assn. *N. Y. Elec. Engr.*, Sept., p. 411.

**Electricity versus Gas in the East.** *Elec. World*, Sept. 14, p. 187.

**Comparative Cost of Electricity and Gas.** *Gas and Water Rev. Lond. Elec. Rev.*, Sept. 13, p. 287

**The Edison Filament Patent in Canada.** *Elec. World*, Sept. 21, p. 200.

**Electric Light in Shafts.** *N. Y. Elec. Rev.*, Sept. 21, p. 1.

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**Influence of Electric Light on Plants.** Dr. Siemens, Roy. Soc. *N. Y. Elec. Rev.*, Sept. 28, p. 1.

**An Open Letter from President Weeks.** *Elec. World*, Sept. 7, p. 166.

**The National Electric Light Association.** *N. Y. Elec. Engr.*, Sept., p. 398.

---

## ELECTRIC LAMPS.

**The Maximum Efficiency of Incandescent Lamps for Central Station Work.** *Lond. Elec. Engr.*, Sept. 6, p, 188; *Lond. Elec. Rev.*, Sept. 6, p 265. (Leigh Carroll at the Edison Convention.)

**Arc Lamps and their Mechanism.** (Concl'd from p. 351.) S. P. Thompson. Soc. Arts. *N. Y. Elec. Engr.*, Sept , p. 383.

**The Wensel Arc Lamp.** (Ill.) *Lond. Elecn.*, Sept. 13. p 481.

**The Hauck Arc Lamp.** (Ill.) *Lond. Elecn* , Sept. 6, p. 460.

**The Efficiency of the Arc Lamp.** Hatsune Nakano, Am. Inst. Elec. Engrs. *Lond. Elec. Rev.*, Sept. 6, p. 273

**An Automatic Electric Reading Lamp.** (Ill.) *Lond Elec. Engr.*, Sept. 6, p. 187.

**Messrs. Ernest Scott & Co's "Tyne" Dynamo and Arc Lamps.** (Ill.) *Lond. Elec. Engr.*, Sept. 20, p. 235.

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## DYNAMOS.

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**The New Wood Arc Light Dynamo Electric Machine.** (Ill.) *N. Y. Elec. Rev.*, Sept. 14, p. 1.

**The Thomson-Houston Alternating Current Dynamo.** (Ill.) *Elec. World*, Sept. 21, p. 197.

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**The Gwynne-Cooper Steam Dynamo.** (Ill.) *Lond. Elec. Rev.*, Sept. 13, p. 290.

**Permanent Magnets in Pole Pieces.** (Corr.) P. H. Vander Weyde. *Elec. World*, Sept. 14, p. 180.

**On Some Mechanical Details of Electrical Machinery.** A. J. Shaw.) *Am. Gas Lt. Jour. Lond. Elecn.*, Sept. 6. p. 449.

**English v. French Dynamos.** *Lond. Elec. Rev.*, Sept. 20, p. 311.

**Methods to Determine the Equivalent Area of Armatures.** Ervin S. Ferry. *Lond. Elec. Engr.*, Sept. 13, p. 213.

**Magnetic Leakage in Dynamos.** H. S. Carhart. *West. Elecn. Lond. Elec. Rev.*, Sept. 13, p. 286.

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**A Synthetic Study of Dynamo Machines.** (Cont'd from p. 65.) *Lond. Elec. Rev.*, Sept. 6, p. 257.

**Notes on the Dynamos at the Paris Exhibition.** (Ill.) *Lond. Elec. Rev.*, Sept. 6, p. 260. Sept. 13, p. 293.

**Dynamo-Electric Machines.** M. Hillairet. *Elec. World*, Sept. 7, p. 171. (Inter. Elec. Conference, Paris, Aug., 1889.)

**The Experimental Determination of the Law of Variation of the Electromotive Force in the Armature of a Westinghouse Dynamo.** L. Searing and S. V. Hoffman. *Elec. World*, Sept. 7, p. 168.

**A New Method of Driving Dynamos by Friction Belting.** (Ill.) *Elec. World*, Sept. 14, p. 183.

**A Practical Method of Driving Dynamos Direct from the Engine Pulley.** (Ill.) (G. F. Evans.) *N. Y. Elec. Rev.*, Sept. 14, p. 8; *Md. Lt. & Ht.*, Sept. 19, p. 343; *Science*, Sept. 27, p. 210.

**Dynamo Progress.** *Lond. Elec. Rev. N. Y. Elec. Rev.*, Sept. 7. p.

## TRANSFORMERS.

**The Design of Transformers.** J. Swinburne, Brit. Assn. *Lond. Elec. Rev.*, Sept 20, p. 314; *Lond. Elec. Engr.*, Sept. 20, p. 226; *Lond. Elecn.*, Sept. 20. p. 492; Sept. 27, p. 523.

**Notes on Transformers.** Charles Steinmetz. *Elec. World*, Sept. 7, p. 168; *Lond. Elec. Engr.*, Sept. 27, p. 255.

**Transformers.** M. Picou, International Elec. Conference, Paris, Aug., 1889. *Elec. World*, Sept. 7, p. 172.

**The Practical Construction of Transformers.** W. F. Collins. *Elec. World*, Sept 7, p. 164.

**Precautions to be Adopted where a Supply of Electricity is Furnished by Means of Transformers.** Killingworth Hedges. Brit. Assn. *Lond. Elecn.*, Sept. 27, p. 532; *Lond. Elec. Rev.*, Sept. 20, p. 320; *Lond. Elec. Engr.*, Sept. 20, p. 236.

## SYSTEMS OF DISTRIBUTION.

**Transmission and Distribution of Motive Power.** *Lond. Elecn.; N. Y. Elec. Rev.*, Sept. 7, p. 6.

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**The Distribution of Energy by Means of Alternating Currents.** (Corr.) M. Leblanc. *Lond. Elecn.*, Sept. 20, p. 508.

**The Five-Wire System.** (Note.) *Elec. World; Lond. Elec. Engr.*, Sept. 13, p. 204.

## ELECTRIC MOTORS, CONTINUOUS.

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**A New Baxter Motor.** (Ill.) *Elec. World*, Sept. 28, p. 215; *N. Y. Elec. Rev.*, Sept. 28, p. 10.

**A New 75 H. P. Electric Motor.** *Elec. World*, Sept. 28, p. 218.

---

ELECTRIC MOTORS, ALTERNATING.

**Alternating Current Motors; The Evolution of a New Type.** (Ill.) F. J. Patten, Am. Inst. Elec. Engrs. *West. Elecn.*, Sept. 28, p. 172; *N. Y. Elec. Rev.*, Sept. 28, p. 1; *Md. Lt. & Ht.*, Sept. 26, p. 366; *Elec. World*, Sept. 28, p. 221.

**The Zipernowski Electrostatic Electro-Motor.** (Ill.) *Lond. Elec. Rev.*, Sept. 27, p. 344.

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---

ELECTRIC POWER.

**The Snelgrove Electric Weighing Machine at the Paris Exposition.** (Ill.) *Elec World*, Sept. 7, p. 164; Sept. 14, p. 186; *West. Elecn.*, Sept. 7, p. 132; *N. Y. Elec. Rev.*, Sept. 7, p. 8.

**Type-Setting by Electric Motor.** (Note.) *Chicago Evening Journal; Lond. Elec. Engr.*, Sept. 13, p. 204.

**The Brush Electrical Hoisting Apparatus.** (Ill.) *Elec. Pr.*, Sept., p. 274.

**The Electric Transfer Table at Fitchburg, Mass.** (Ill.) *Elec. World*, Sept., 21, p. 201; *Science*, Sept. 13, p. 173.

**Power Plant of the Oerlikon Works at the Paris Exposition.** *Elec. Pr.*, Sept, p. 288.

**The Crompton Electric Crane.** (Ill.) *West. Elecn.*, Sept. 14, p. 147; *N. Y. Elec. Rev.*, Sept. 14, p. 3.

**Electric Power in the South.** *Mfrs. Record; N. Y. Elec. Rev.*, Sept. 28, p. 6.

**The Application of Electricity to Coal Mining.** *Colliery Engr.; Elec. Pr.*, Sept., p. 284.

**Electric Bridges at the Paris Exhibition.** *Md. Lt. & Ht.*, Sept. 5, p. 292.

**Electric Power Transmission.** R. H. Smith. *Indust.; West. Elecn.*, Sept 14, p. 149.

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**Records by the Electric Launch "Eta."** (Note.) *Lond. Elec. Engr.*, Sept. 20, p. 225.

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**Electric Launches on the Thames.** G. Forbes, Brit. Assn. *Lond. Elec. Engr.*, Sept. 27, p. 258; *Lond. Elecn.*, Sept. 20, p. 504.

**Submarine Torpedo Boats.** *N. Y. Elec. Rev.*, Sept. 7, p. 2.

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## ELECTRIC RAILWAYS.

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**The Rochester and Charlotte Electric Railway.** *N. Y. Elec. Rev.*, Sept. 7, p. 3; *Md. Lt. & Ht*, Sept. 5, p. 293.

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**The Electric Tram Line at Buda-Pesth.** *Lond. Elec. Rev.*, Sept, 13, p. 289.

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**Electric Traction by Storage Batteries.** *Lond. Elec. Rev.*; *West. Elecn.*, Sept. 21, p. 163.

**Electric Traction by Storage Batteries.** Wm. Bracken, Nat'l Elec. Lt. Assn. *N. Y. Elec. Engr.*, Sept., p. 410; *Elec. Pr.*, Sept., p 276.

**Success of the Storage Battery Cars on the Fourth and Madison Avenues, N. Y.** (Ill.) *Elec Pr.*, Sept., p. 285.

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**Electric Traction** (Corr.) A. J. Jarman. *Lond. Elec. Rev.*, Sept. 20, p. 340.

**Advantages of Electricity over Horses for Street Railways.** H. M. Whitney. (West End Ry. Co., Boston) *Elec. Pr.*, Sept., p. 271.

**Sprinkling Electric Railways.** *West. Elecn.*, Sept. 7, p. 137. E. D. Priest.)

**Electric Railways.** G. W. Mansfield. Nat. Elec. Lt. Assn. *Lond. Elec. Engr.*, Sept., p. 412; *Elec. Pr.*, Sept., p. 279; *Lond. Elec. Engr.*, Sept. 6, p. 196; Sept. 13, p. 214.

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**A Substantial Rail Chair.** (Ill.) *N. Y. Elec. Rev.*, Sept. 21, p. 12. (R. T. White.)

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INSTRUMENTS, MEASUREMENTS. &c.

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**The Kilowatt.** W. H. Preece. *Lond. Elecn.*, Sept. 6, p. 456.

**A New Thermometric Scale.** G. Forbes and W. Preece, Brit. Assn. *Lond. Elecn.*, Sept. 20, p. 495.

**Depres-D'Arsonval Differential Galvanometer.** (Ill.) *Lond. Elec. Rev.*, Sept. 27, p. 350.

**Dynamo Room Accessories for Intensity, Potential and Resistance Measurements.** (Ill.) C. C. Haskins, Nat. Elec. Lt. Assn. *Lond. Elec. Rev.*, Sept. 6, p. 271.

**Electrical Standards.** M. Pellat. (Report prepared for the International Electrical Conference of Paris, Aug., 1889.) *Elec. World*, Sept. 7, p. 170; *Lond. Elecn.*, Sept. 13, p. 476.

**A New Pocket Galvanometer.** (Ill.) *N. Y. Elec. Rev.*, Sept. 7, p. 3. (Chas. Plumb.)

**Measurements of Energy.** M. A. Potier. (Report prepared for the Inter-Elec. Con., Paris, Aug. 1889.) *Elec. World*, Sept. 7, p. 171; *Md. Lt. & Ht*, Sept. 12, p. 314.

**Woodhouse and Rawson Wiring Tables.** *Lond. Elec. Rev.*, Sept. 27, p. 360.

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**On Chenoweth's Electric Conduits.** *Fkln. Ins. Jour. Lond. Elec. Rev.*, Sept. 13, p. 284; *Lond. Elecn.*, Sept. 27, p. 521.

**Underground Construction in Brooklyn.** J. C. Reilly. Nat. Tel. Con. *West. Elecn.*, Sept. 21, p. 156; *N. Y. Elec. Rev.*, Sept. 21, p, 10; *Md. Lt. & Ht.*, Sept. 19, p. 338; *Elec. World*, Sept. 21, p. 207.

**Edison Underground System.** (Ill.) *West. Elecn.*, Sept. 7, p. 129.

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**The Carhart-Clark Standard Cell.** *Elec. World*, Sept. 7, p. 162; Sept. 14. p. 184.

**An Improved Standard Clark Cell with Low Temperature Coefficient.** H. S. Carhart. *Elec. World*, Sept. 7, p. 162; *Science*, Sept. 6, p. 159; *West. Elecn.*, Sept. 14, p. 145.

**A Novel Electric Battery.** *Revista Technica; Science*, Sept. 13, p. 174.

**Primary Batteries.** (Note.) *Lond. Elec. Engr.*, Sept. 27, p. 243, (W. L. Silvey.)

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## SECONDARY BATTERIES.

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**Secondary Batteries at the Paris Exhibition.** *West. Elecn.*, Sept. 14, p. 148.

**The Porosity of Secondary Battery Plates.** E. R. Knowles. *Elec. World*, Sept. 28, p 214.

**The Nature of Secondary Batteries.** (Corr.) Geo. B. Prescott, Jr. *Elec. World*, Sept. 28, p. 218.

**What Constitutes a Storage Battery.** (Corr.) E. R. Knowles. *Elec. World*, Sept. 21, p. 196.

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## ELECTROLYSIS.

**Note on the Electrolysis of Distilled Water.** M. E. Duler. *Elec. World*, Sept. 7, p. 168.

**On Electrolytic Polarisation by Metals.** M. N. Piltschikoff. *Comptes Rendus; Lond. Elec. Rev.*; Sept. 6, p. 279.

**Purification of Sewage and Contaminated Water by Electrolysis.** W. Webster. *Lond. Elec. Engr.*, Sept. 27, p. 246.

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## THERMO-ELECTRICITY.

**Thermo-Electric Investigations.** H. Stroud, Brit. Assn. *Elec. World*, Sept 28, p. 220; *Lond. Elec. Rev.*, Sept. 20, p 319; *Lond. Elecn.*, Sept. 27, p. 519.

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**"Jump" Lightning Arrester with Fuse Wire.** (Ill.) W. W. L. *Elec. World*, Sept. 21, . 198.

**A New Lightning Arrester.** Foree Bain. *West. Elecn.*, Sept. 7, p. 133; *N. Y. Elec Rev.*, Sept. 14. p. 7.

**Method of Taking Photographs of Lightning Flashes.** W. Marriott. *Elec. World*, Sept. 14, p. 183.

**An Improved Lightning Protector.** (Ill.) A. R. Bennett. *Lond. Elecn; Elec. World*, Sept. 7, p. 168.

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## MISCELLANEOUS.

**The Modern Theory of Light.** O. Lodge. *Liverpool Univ. Coll. Mag. Lond. Elecn.*, Sept. 6, p. 447.

**On Hysteresis in the Relation of Strain to Stress.** J. A. Ewing. Brit Assn *Lond. Elec. Engr.*, Sept. 27, p. 259; *Lond. Elecn.*, Sept. 20, p. 499; *Lond Elec. Rev.*, Sept. 20, p. 320.

**The Dangers of Electricity.** (Note.) *Lond. Times; Lond Elec. Engr.*, Sept 27, p. 244 (W. H. Preece.)

**On the Relative Effects of Steady and Alternate Currents on Different Conductors.** W. H. Preece. Brit. Assn. *Elec. World*, Sept. 28, p. 220; *Lond Elecn.*, Sept. 20. p. 502

**Curious Effects of Metallization in a Vacuum.** (Ill.) *Revue Internationale de l'Electricite; Lond. Elec. Rev.*, Sept. 6, p. 256; *Elec. World*, Sept. 28, p. 218.

**The Heating of Conductors by Electric Currents.** A. E. Kennelly. Edison Convention *Lond. Elec Engr.*, Sept. 6, p. 195.

**The Value of Economic Data to the Electrical Industry.** A. R. Foote. Nat. Elec. Lt. Assn. *N. Y. Elec. Engr.*, Sept., p. 399.

**The Direct Production of Electricity.** *Elec. World*, Sept. 7, p. 163. (Mond.)

**Electricity in Coast Defence.** *St. Nicholas; N. Y. Elec. Rev.*, Sept. 14, p. 3.

**Some of the Hygienic Advantages of Modern City Buildings with Special Reference to the Respiratory Organs.** W. S. English. State Sanitary Con. *Md. Lt. & Ht*, Sept. 26, p 363.

**Electro-Physiology.** *Md Lt. & Ht*, Sept. 26, p. 364.

**Cause of Thunder.** J. M. Tyler. *West. Elecn.*, Sept. 14, p. 148.

**A Summary of the Differences between Positive and Negative Electricity.** *Comtes Rendus; Lond. Elecn.*, Sept. 6, p. 456.

**The Electro-Magnetic Effects of a Moving Charge.** (Ill.) (Corr.) Oliver Heaviside. *Lond. Elecn*, Sept 6, p. 458.

**A New Insulating Substance.** (Note.) *La Lum. Elect.; Lond. Elecn.*, Sept. 13, p. 465.

**The E. M. F. due to the Action of Light on Selenium.** *Eclairage a l'Electricite; Lond. Elecn.*, Sept. 13, p. 481.

**On the Propagation of Electric Waves through Wires.** (Ill.) H. Hertz *Phil. Mag.; Lond. Elecn*, Sept. 13, p. 473.

**Electrification of Air by Combustion.** (Ill.) M. McLean and Makita Goto. *Lond. Elecn.*, Sept. 20, p. 500.

**On Magnetic Viscosity in Iron.** (Ill.) J. A. Ewing. Roy. Soc. *Lond. Elecn.*, Sept. 27, p. 526.

**"The Dangers of Electricity."** *Lond. Elecn.*, Sept. 27, p. 536.

**Review of Theories of Electrical Action.** H. S. Carhart. Am. Assn. Ad. Sci. *Lond. Elec. Rev.*, Sept. 27, p. 345; *N. Y. Elec. Engr.*, Sept., p. 380.

**On the E. M. F. Produced by an Abrupt Variation of Temperature at the Point of Contact of Two Portions of the Same Metal.** Henry Stroud. Brit. Assn. *Lond. Elec. Engr.*, Sept. 20, p. 237.

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**Electricity as a Profession.** *Lond. Elec. Rev.*, Sept. 6, p. 265.

**The Approaching End of Electrocution.** *Lond. Elec. Rev.*, Sept. 13, p. 291.

**Execution by Electricity.** *Lond. Elec. Rev.*, Sept. 20, p. 330.

**The Manufacture of the Alloys of Aluminum in the Electric Furnace.** J. H. Dagger. *Lond. Elec. Rev.*, Sept. 27, p. 355.

**Electricity: Its Present and its Future.** *Lond. Elec. Rev.*, Sept. 27, p. 369.

**Electrical Surgings: An Experiment.** J. E. Davies. *West. Elecn.*, Sept. 7, p. 136; *Lond. Elec. Rev.*, Sept. 27, p. 349.

**Messrs. W. T. Goolden & Co's Works.** (Ill.) *Lond. Elec. Rev.*, Sept. 20, p. 311.

**Electric Tabulating System** (Note.) *School of Mines Quarterly; Lond. Elec. Engr.*, Sept. 13, p. 205.

**The Thomson Electric Welding Company.** *Md. Lt. & Ht.*, Sept. 5, p. 290.

**Electro-Magnetic Separation of Gold.** (Ill.) *N. Y. Elec. Rev.*, Sept. 28, p. 7. (S. H. Emmens.)

**Improved Electric Bell.** (Ill.) *West. Elecn.*, Sept. 28, p. 171. (Elec. Sup. Co.)

**French Tanners Using the New Process.** *N. Y. Elec. Rev.*, Sept. 14, p. 3.

**Drop-Forged Commutator Bars.** (Ill.) *N. Y. Elec. Rev.*, Sept. 7, p. 9.

**An Improved Magnet Spool.** *Elec. World*, Sept. 14, p. 179. (G. D. Clarke.)

**An Electro-Medical Vaporizer.** *Elec. World*, Sept. 14, p. 182. (Dr. Telschow).

**An Improvement in Switches and Fuse-Boxes.** (Ill.) *Elec. World*, Sept. 14, p. 186.

**A New Electric Exploder.** *Elec. World*, Sept. 21, p. 198. (Maret Bros.)

**The Clarke Instrument Protector.** (Ill.) *Elec. World*, Sept. 14, p. 187.

**The Small-Goodson Electro-Matrix Machine.** *Springfield Republican; Elec. World*, Sept. 14, p. 183.

**A New Automatic "Nickel in the Slot."** (Ill.) *Elec. World*, Sept. 7, p. 167.

**Electro-Magnetic Permutation Lock.** (Ill.) *N. Y. Elec. Rev.*, Sept. 28, p. 1. (Sedgwick's.)

**Julian's Electric Alarm Gauge.** (Ill.) *Lond. Elec. Engr.* Sept. 6, p. 192.

**Riesenberg's Electric Alarm Advance Car.** (Ill.) *Elec. World*, Sept. 7, p. 169.

**The Telephote.** *West. Elecn.*, Sept. 7, p. 133.

**The "Unique" Electric Alarm Clock.** (Ill.) *Elec. World*, Sept. 21, p. 201.

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**The Hall Process for the Manufacture of Aluminum.** *N. Y. Elec. Rev.*, Sept. 14, p. 1; *Elec. World*, Sept. 21, p. 198.

**American International Electrical Conference of 1892.** *Lond. Elec. Rev.*, Sept. 6, p. 259.

**The British Association at Newcastle.** *Lond. Elec. Engr.*, Sept. 13, p. 206.

**Messrs. Crompton's Exhibit at Paris.** (Ill.) *Lond. Elecn.*, Sept. 20, p. 509.

**A Visit to the Institute of Medical Electricity.** (Ill.) *Lond. Elecn.*, Sept. 20, p. 490

**The Meeting of the British Association.** *Lond. Elecn.*, Sept. 20, p. 498.

**The World's Fair.** *West. Elecn.*, Sept. 14, p. 143.

**Electricity at the Rose Polytechnic Institute, Terre Haute, Ind.** *Elec. World*, Sept. 7, p. 163.

**Electricity at the American Association Meeting.** H. S. Carhart. *Elec. World*, Sept. 21, p. 197.

**The Reception to Edison in Paris.** *Elec. World*, Sept. 14, p. 185.

**Universal Electrical Exposition at St. Louis.** *West. Elecn.*, Sept. 7, p. 129; Sept. 14, p. 141; *N. Y. Elec. Rev.*, Sept. 28, p. 6; *Elec. World*, Sept. 28, p. 224.

**Edison and his Inventions at the Paris Exposition.** (Ill.) W. J. Hammer. *Elec. World*, Sept. 7, p. 165; Sept. 14, p. 181; Sept. 21, p. 195; Sept. 28, p. 219.

**The International Electrical Conference at Paris.** *Elec. World*, Sept. 14, p. 188; Sept. 21, p. 202.

**The Paris Exhibition.—Edison Electric Company.** (Ill.) Elihu Thomson. *Lond. Elecn.*, Sept. 6, p. 446; Sept. 13, p. 468.

**International Congress of Electricians Held at Paris, 1889.**

*Lond Elec. Rev.*, Sept., 13, p. 301; Sept. 20, p. 334: Sept. 27, p. 365; *Lond. Elec. Engr.*, Sept. 6, p. 186; *Lond. Elecn.*, Sept. 6, pp. 450, 451; Sept. 13, p 470; *West. Elecn.*, Sept 7, p. 131; Sept 14, p 149; Sept. 28, p. 165.

**Address to the Mechanical Science Section of the British Association.** W. Anderson, *Lond. Elec. Engr.*, Sept. 27, p. 255; *Lond. Elec. Rev*, Sept. 20, p. 322.

**The Birmingham Exhibition.** (Ill.) *Lond. Elec. Rev.*, Sept. 6, p. 288; *Lond. Elecn.*, Sept. 27, p. 518; *N. Y. Elec. Rev.*, Sept. 7, p. 1.

**Henry Metsger** (with Portrait). *West. Elecn.*, Sept. 14, p. 141.

**Electrical World Portraits. VII.** Frank J. Sprague, *Elec. World*, Sept. 7, p. 163.

**Electrical World Portraits. VIII.** Thomas D. Lockwood. *Elec. World*, Sept. 14, p. 178.

**A Biographical Sketch of E. E. N. Mascart** (with Portrait). *Elec. World*, Sept. 28, p. 214.

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## MECHANICAL.

**A New Governor for Electric Light Engines.** (Ill.) *Lond. Elecn.*, Sept. 6, p. 461.

**Bristol's Steel Belt Fastener.** (Ill.) *Elec. Pr.*, Sept., p. 287.

**Jonson's New Compound Stationary Engine.** (Ill.) *Elec. World*, Sept. 7, p. 169.

**The Kriebel Duplex Engine for Electric Lighting.** (Ill.) *Elec. World*, Sept. 21, p. 200.

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## Reference List of Leading Authorities Cited in the Index of Current Electrical Literature.

| NAME. | ABBREVIATION. | PUBLISHED, &c. |
|---|---|---|
| Engineer. | *Engr.* | London, 163 Strand. weekly. £1.9. |
| Engineering. | *Eng.* | London, 35–36 Bedford St. W. C.; weekly. £1.16. |
| Industries. | *Indust.* | 358 Strand, London W. C. weekly. £1.12. |
| The Electrician. | *Lond. Elecn.* | London, 1 Salisbury Court, E. C.; weekly. £1 2. |
| The Telegraphic Journal and Electrical Review. | *Lond Elec. Rev.* | London, 22 Paternoster Row, E. C.; weekly. £1.1 8. |
| The Electrical Engineer | *Lond. Elec. Engr.* | London, 139–140 Salisbury Court; weekly, 17s. 4d. |
| Nature. | *Nat.* | London, 29 Bedford St., W. C.; weekly, £1.8. |
| The Electrical Engineer | *N. Y. Elec. Engr.* | New York, 150 Broadway; monthly, $3 |
| The Electrical World. | *Elec. World.* | New York, 167–177 Times Building; weekly. $3 |
| The Electrical Review. | *N. Y. Elec. Rev.* | New York, 13 Park Row; weekly. $3. |
| The Electric Age. | *Elec. Age.* | New York, 5 Dey Street; semi-monthly, $1.50. |
| Modern Light and Heat. | *Md Lt and Ht.* | Boston, 146 Franklin Street; weekly, $3. |
| Western Electrician. | *West. Elecn.* | Chicago, 6 Lakeside Building; weekly, $3 |
| Electric Power. | *Elec. P'wr.* | New York, 132 Nassau St. monthly, $3. |
| The Electro-Mechanic. | *Elec. Mech.* | Kansas City, Mo.; semi-monthly, $2. |
| Practical Electricity. | *Prac. Elec.* | Boston, 620 Atlantic Ave.; monthly, $2. |
| Journal of the Franklin Institute. | *Jour. Fkln. Inst.* | Philadelphia, Franklin Institute, monthly, $5. |
| Science. | *Science.* | New York, 47 Lafayette Place, weekly, $3 50. |
| Scientific American. | *Sci. Am.* | New York, 361 Broadway; weekly, $3. |
| Scientific American Supplement. | *Sci. Am. Supp.* | New York, 361 Broadway; weekly, $5. |
| Mechanics. | *Mech.* | Philadelphia, 907 Arch St.; monthly, $1. |
| Railroad Gazette. | *R'd. Gaz.* | New York, 73 Broadway; weekly, $4 20. |
| Street Railway Journal | *St. Ry. Jour.* | New York, 113 Liberty St.; monthly, $2 |
| Street Railway Gazette. | *St. Ry. Gaz.* | Chicago, 9 Lakeside Building: monthly, $2. |
| Light, Heat and Power | *Lt. Ht. and Pr.* | Philadelphia, Drexel Building; weekly, $4. |
| Progressive Age. | *Prog. Age.* | New York, 18 Broadway; semi-monthly, $2. |
| Railroad and Engineering Journal. | *Rd. and Eng. Jour.* | New York, 45 Broadway; monthly, $3. |

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# AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

# LIST OF MEMBERS.

MAY 1ST, 1890.

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## HONORARY MEMBERS.

| Name. | Address. | Date of Membership. |
|---|---|---|
| PREECE, WM. H. *F. R. S.* | Electrician, General Post Office, London, Eng. Residence, Gothic Lodge, Wimbledon. | Oct. 21, 1884 |
| GREEN, DR. NORVIN | (*Past President*). Pres't Western Union Telegraph Co., 195 Broadway, New York. | A April 15, 1884<br>M Oct. 21, 1884<br>H.M. Dec. 3, 1889 |

## MEMBERS.

| | | |
|---|---|---|
| ACHESON, EDW. G. | Electrician, Box 952, Pittsburgh, Pa. | A Jan. 3, 1888<br>M May 1, 1888 |
| AHRARN, T. | Ahearn & Soper, Electrical Supplies, Ottawa, Ont. | A July 12, 1887<br>M Sept. 6, 1887 |
| ANTHONY, PROF. W. A. | Consult'g Electrician. The Mather Electric Co., Manchester, Conn. | A Dec. 9, 1884<br>M Jan. 6, 1885 |
| BATCHELLER, B. C. | Superintendent of the Pneumatic Dynamite Gun Co., 71 Broadway, New York. | A Sept. 6, 1887<br>M Nov. 1, 1887 |
| BATCHELOR, CHAS. | Electrical Engineer, 33 West Twenty-fifth St., New York. | A June 8, 1887<br>M July 12, 1887 |
| BATES, J. H. | Box 2702, New York. | A Sept. 6, 1887<br>M Oct. 1, 1889 |
| BATES, MAURICE E. | Manager, Western Electric Construction Co., 503 Delaware St., Kansas City, Mo. | A Aug. 6, 1889<br>M Oct. 1, 1889 |
| BAYLY, B. | Surveyor and District Engineer, Western District Colonial Gov't. Cape Town, Cape of Good Hope, Africa. | A Oct. 4, 1887<br>M Dec. 6. 1887 |
| BELL, PROF. A. GRAHAM | 1336 Nineteenth St., Washington, D. C. | A April 15, 1884<br>M Oct. 21, 1884 |
| BERNARD, EDGAR G. | Electrical Engineer, Utica, N. Y. | A Jan 5, 1886<br>M July 12, 1887 |
| BIRDSALL, E. T. *M. E.* | Electrical Engineer, 115 Broadway, New York. | A June 8, 1887<br>M Nov. 1, 1887 |
| BLAKE, EDWARD | Treasurer of New England Electric Co., 55 Oliver St., Boston, Mass. | A May 24, 1887<br>M Sept. 3. 1889 |

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| Name. | Addr ss, | Date of Membership. |
|---|---|---|
| BLAKE, FRANCIS | Auburndale, Mass. | A Sept. 3, 1889<br>M Oct. 1, 1889 |
| BLODGETT, GEO. W. | Electrical Engineer B. & A R. R. and Consulting Electrician, Boston, Mass | A July 12, 1887<br>M Sept. 6, 1887 |
| BOSCH, ADAM | Sup't, Fire Alarm Telegraph. Newark N. J. | A April 15, 1884<br>M Jan. 6, 1885 |
| BRADLEY, CHAS. S. | Electrical Engineer. Yonkers, N. Y. | A May 24, 1887<br>M Dec. 6, 1887 |
| BROWN, JO. STANFORD | Electrical Engineer, with Daft Electric Light Co., 115 Broadway, New York. | A Sept. 6, 1887<br>M Nov. 1, 1887 |
| BRUSH, CHAS. F. | Electrical Engineer. 956 Euclid Ave, Cleveland, O. | A April 15, 1884<br>M Oct. 21, 1884 |
| BYLLESBY, HENRY M. | Vice-President and Gen'l Manager, Westinghouse Electric Co., Pittsburgh. Pa. | A Sept. 7, 1888<br>M Oct. 2, 1888 |
| CARROLL, LEIGH | President and General Manager, The Edison Electric Illuminating Co., Birmingham, Ala | A Oct 1, 1889<br>M Nov. 12, 1889 |
| CHAMBERLAIN, J. C. | Supt. Julien Electric Traction Co., 135 East Eighteenth St., New York. | A Dec. 6, 1887<br>M Jan. 3, 1888 |
| CHEEVER, CHAS. A. | 13 Park Row, New York. | A April 15, 1884<br>M Oct. 21, 1884 |
| CHURCH, WM. LEE | Member of Westinghouse, Church, Kerr & Co., Engineers, 620 Atlantic Ave., Boston, Mass. | A April 5, 1887<br>M May 17, 1887 |
| CLARK, ERNEST P. | Electrical Engineer, 192 Broadway, New York. | A Jan. 8, 1887<br>M Nov. 1, 1887 |
| CLARKE, CHAS. L. | Mechanical and Electrical Engineer, 55 Liberty St., New York. | A April 15, 1884<br>M Jan. 6, 1885 |
| COLBY, EDWARD A. | Electrician of the Weston Electrical Instrument Co., 606 High St., Newark, N. J. | A April 2, 1889<br>M May 7, 1889 |
| CONANT, THOMAS P. | General Supt. of Construction, United Edison Mfg. Co., 65 Fifth Ave., New York. | A Nov. 1, 1887<br>M Jan. 3, 1888 |
| ONDICT, G. HERBERT | General Manager, The Electric Car Co. of America, 4720 Green St., Germantown, Pa. | A July 12, 1887<br>M Sept. 6, 1887 |
| COTHREN, WM. H. | Sup't of Wiring Department, Edison Electric Illuminating Co., 432 Fifth Ave., New York. | A Aug. 6, 1889<br>M Oct. 1, 1889 |
| COWLES, ALFRED H. | Technical Adviser to the Cowles Smelting and Aluminum Co., Lockport, N. Y. | A Mar. 5, 1889<br>M May 7, 1889 |
| CROCKER, FRANCIS B. | (*Manager*). Instructor in Electrical Engineering, School of Mines Columbia College, New York. | A May 24, 1887<br>M April 2, 1889 |
| CROSS, CHAS. R. | Thayer Professor of Physics, and Director of the Rogers Laboratory, Mass. Institute of Technology, Boston, Mass. | A April 15, 1884<br>M Oct. 21, 1884 |
| CUTTRISS, CHAS. | (*Manager*). Electrician, The Commercial Cable Co., 1 Broad St., New York. | A Nov. 1, 1887<br>M Dec. 6, 1887 |

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| Name. | Address. | Date of Membership. |
|---|---|---|
| DAFT, LEO | Electrician, Plainfield, N. J. | A Dec. 9, 1884<br>M Jan. 6, 1885 |
| DANVERS, ALAN | Managing Director and Chief Electrician, The Anglo-Portugese Telephone Co., L't'd. 60 Travessa Santa Justa, Lisbon, Port'l. | A Nov. 1, 1887<br>M Sept. 3, 1889 |
| DANVERS, ERNESTO | Electrical Engineer, Casilla 74, Rosario, Argentine Republic. | A Jan. 3, 1888<br>M May 1, 1888 |
| DAVIES, JOHN E. | Professor of Physics, University of Wisconsin, 523 Carroll St. Madison, Wis | A Jan. 7, 1890<br>M Mar. 18, 1890 |
| DELAFIELD, A. FLOYD, | *Ph.D.* Electrical Engineer, Noroton, Conn. | A May 7, 1889<br>M Oct. 1, 1889 |
| DICKENSON, SAMUEL S. | Sup't, Commercial Cable Co., Hazel-Hill, Guysborough Co., N.S. | A Mar. 6, 1888<br>M Oct. 1, 1889 |
| DIEHL, PHILIP | Inventor, Singer Sewing Machine Co., Elizabeth, N. J. | A April 15, 1884<br>M Dec. 9, 1884 |
| D'INFREVILLE, GEORGES | Electrical Engineer and Expert 110 Liberty St., New York. | A Nov. 1, 1887<br>M Dec. 6, 1887 |
| DOIJER, H. | 34 Woburnsquare, W. C., London, Eng. | A Jan. 7, 1890<br>M Mar. 18, 1890 |
| DUDLEY, CHARLES B. | Chemist and Scientific Expert, Penn. R. R. Co, 1219 Twelvth Ave., Altoona, Pa. | A Oct. 1, 1889<br>M Nov. 12, 1889 |
| DUNCAN, DR. LOUIS | (*Vice-President*). Johns Hopkins University, Baltimore, Md. | A July 12, 1887<br>M Sept. 6, 1887 |
| DYER, R. N. | Patent Attorney. 40 Wall St., New York. | A July 12, 1887<br>M Sept. 6, 1887 |
| EDISON, THOMAS A. | Electrician and Inventor, Orange, N. J. | A April 15, 1884<br>M Oct. 21, 1884 |
| FARNHAM, ISAIAH H. | Electrician for the N. E. Telephone & Telegraph Co., 50 Pearl St., Boston, Mass. | A June 8, 1887<br>M July 12, 1887 |
| FIELD, C. J. | President and General Manager Field Engineering Co., 15 Cortlandt St., New York. | A June 8, 1887<br>M Nov. 1, 1887 |
| FIELD, STEPHEN D. | Electrician and Inventor, Stockbridge, Mass. | A April 15, 1884<br>M Oct. 21, 1884 |
| FITCH, D. H. | President, The Fitch Battery and Electric Co., Cazenovia, N. Y. | A Sept. 3, 1889<br>M Oct. 1, 1889 |
| FLEMING, WILFRID H. | Care of Howard Fleming, Park Ave., Plainfield, N. J. | A Dec. 6, 1887<br>M Jan. 3, 1888 |
| FOSTER, HORATIO A. | Electrical Engineer, 45 East Twenty-second St., New York. | A June 8, 1887<br>M Sept. 6, 1887 |
| FREEMAN, DR. FRANK L. | Attorney-at-Law, Solicitor of Patents, Electrical Expert, 931 F St., Washington, D. C. | A May 7, 1889<br>M Sept. 3, 1889 |
| GARRATT, ALLAN V. | Secretary and Treasurer of the National Electric Light Association, 18 Cortlandt St., New York. | A April 2, 1889<br>M May 7, 1889 |
| GARVER, M. M. | 48 Walnut St., Newark, N. J. | A July 10, 1888<br>M Sept. 3, 1889 |
| GEYER, PROF. WM. E. | (*Manager*). Stevens Institute of Technology, Hoboken, N. J. | A June 5, 1888<br>M Sept. 7, 1888 |

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|---|---|---|
| GISBORNE, HARTLEY, *C. E.* | District Superintendent and Electrician, Government Telegraph Service of Canada, Qu'Appelle Station. Assa., N. W. Territory, Canada. | A Dec. 9, 1884<br>M May 17, 1887 |
| GRISCOM, WM. W. | Haverford College P. O., Montgomery Co., Pa. President, The Electro Dynamic Co., 224 Carter St., Philadelphia and Managing Electrician The Electrical Accumlator Co., New York. | A June 5, 1888<br>M Mar. 18, 1890 |
| HALL, CLAYTON C. | Civil Engineer, 810 Park Ave., Baltimore, Md. | A April 15, 1884<br>M Oct. 21, 1884 |
| HAMBLET, JAMES | Manager Time Service, W. U. Tel. Co., 195 Broadway, P. O. Box 3393, New York. | A Nov. 1, 1887<br>M Dec. 6, 1887 |
| HAMILTON, GEO. A. | Electrician, Western Electric Co., 22 Thames cor. Greenwich St., New York. | A April 15, 1884<br>M Oct. 21, 1884 |
| HAMMER, W. J. | Electrical Engineer, 23 Rowland St, Newark, N. J. | A June 8, 1887<br>M July 12, 1887 |
| HANCOCK, WM. J.<br>† | Supt. of Telephones, Dept. of Public Works, Perth, Western Australia. | A Jan. 7, 1890<br>M Mar. 18, 1890 |
| HASKINS, CHARLES H. | Electrician care of New York Club, Fifth Ave and Thirty-fifth St., New York. | A April 15, 1884<br>M Oct, 21, 1884 |
| HAYES, HAMMOND V. | Electrician, American Bell Telephone Co, Boston, Mass. 127 Purchase St.. Cambridge. Mass. | A Nov. 12, 1889<br>M Mar. 18, 1890 |
| HAYNES, F. T. J. | Divisional Telegraph Engineer, Great Western Railway, Taunton, Eng. | A Dec. 6, 1888<br>M Jan. 3, 1887 |
| HAZARD, COL. ROWLAND R. | N. Y. District Railway Co., 120 Broadway, New York. | A April 15, 1884<br>M Oct. 21, 1884 |
| HERING, CARL | Consulting Electrical Engineer, 3816 Spring Garden St, Philadelphia, Pa. | A Jan. 3, 1888<br>M June 5, 1888 |
| HERZOG. DR. F. BENEDICT | (*Manager*) President Herzog Teleseme Co., 30 Broad St., New York. | A May 24, 1887<br>M July 12, 1887 |
| HIGGINS, EDWARD E. | Electrical Engineer, 202 Main St., Buffalo, N. Y. | A June 8, 1887<br>M July 12, 1887 |
| HOUSTON, PROF. EDWIN J. | 1521 Mt. Vernon St., Philadelphia, Pa. | A April 15, 1884<br>M Oct. 21, 1884 |
| HOWELL, JOHN W. | (*Manager*). Electrician, Edison Lamp Co., Harrison N. J. | A July 12, 1887<br>M June 5, 1888 |
| HOWELL, WILSON S. | Electrical Expert. Central Station, Edison Elec. Light Sysem, New Brunswick, N. J. | A Sept. 3, 1889<br>M Mar. 18, 1890 |
| HUNTER, RUDOLPH M. | Mechanical and Elect'al Engineer, 926 Walnut St., Philadelphia, Pa | A July 13, 1886<br>M May 17, 1887 |
| HYDE, JEROME W. | Springfield, Mass. | A June 8, 1887<br>M Nov. 1, 1887 |
| JANNUS, FRANKLAND | Solicitor of Patents, 928-30 F. St Washington, D. C. | A Nov. 12, 1889<br>M Mar. 18, 1890 |
| JENKS, W. J. | Technical Department, United Edison Manufacturing Co., 44 Wall Street, New York. | A June 8, 1887<br>M Nov. 1, 1887 |

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| Name. | Address. | Date of Membership. |
|---|---|---|
| JOHNSON, E. H. | President, Sprague Electric Railway & Motor Co., 16 Broad St., New York. | A Feb. 7, 1888<br>M May 1, 1688 |
| JONES, FRANCIS W. | Assistant Gen'l-Manager and Electrician, Postal-Telegraph Cable Co., 187 Broadway, New York. | A April 15, 1884<br>M Oct. 21, 1884 |
| KNOWLES, E. R. | Electrical Engineer, 439*a* Waverly Ave., Brooklyn, N. Y. | A June 8, 1887<br>M July 12, 1887 |
| KNUDSON, A. A. | Electrican, 39 Nassau St., New York. | A Dec. 6. 1887<br>M Jan. 3, 1888 |
| LANGE, PHILIP A. | Superintendent of Detail Department, Westinghouse Electric Co., Pittsburgh, Pa. | A Mar. 6, 1888<br>M June 5, 1888 |
| LANGTON, JOHN | General Manager, Canadian Edison M'f'g Co., Sherbrooke, P. Q. | A Mar. 6, 1888<br>M June 5. 1888 |
| LATTIG, J. W. | Sup't Telegraph, Lehigh Valley R. R., South Bethlehem, Pa | A June 8, 1887<br>M July 12, 1887 |
| LEONARD, H. WARD | General Manager, United Edison Manufacturing Co., 65 Fifth Ave., New York. | A July 12, 1887<br>M Sept. 6, 1887 |
| LEONARD, M. B. | Electrical Engineer, and Supt. of Telegraph, Chesapeake & Ohio R'y. Co., Richmond, Va. | A Nov. 6, 1886<br>M May 1, 1888 |
| LIEB, JOHN W., JR. | Chief Engineer, Società Generale Italiana di Elettricita (Sistema Edison). Via S. Radigonda N. 4, Milan, Italy. | A Sept. 6, 1887<br>M Nov. 1, 1887 |
| LOCKWOOD, THOMAS D. | (*Manager*). Electrical Engineer. and Advisory Electrician. P. O., Drawer 2, Boston, Mass. | A April 15, 1884<br>M Oct. 21, 1884 |
| LYNE, LEWIS F. | Mechanical and Elect'al Engineer, 307 Grove St., Jersey City, N. J. | A Jan. 3, 1888<br>M June 5, 1888 |
| MAILLOUX, C. O. | Consulting Electrical Engineer, 32 Liberty St., New York. | A April 15, 1884<br>M Oct. 21, 1884 |
| MARKS, WILLIAM DENNIS, | *Ph. B., C. E.* Edison Electric Light Co., Philadelphia, Pa. | A Feb. 7, 1888<br>M May 1, 1888 |
| MARSHALL, J. T. | Inspector of Lamp Manufacture, Edison Lamp Co., Harrison, N. J. | A Oct. 1, 1889<br>M Nov. 12, 1889 |
| MAYNARD, GEO. C. | Electrical Engineer, 1409 New York Ave., Washington, D. C. | A April 15, 1884<br>M Dec. 9. 1888 |
| MILLIS, JOHN | Lieutenant of Engineers, U. S. Army, P.O. Box 2128, New York. | A July 7, 1884<br>M Mar. 3, 1885 |
| MILLS, FRANK P. | Superintendent Cleveland Iron Mining Co., Ishpeming, Mich. | A Jan. 6, 1885<br>M Mar. 3. 1885 |
| NICHOLS, EDWARD L. | (*Vice-President*). Professor of Physics, at Cornell University, Ithaca, N. Y. | A Oct. 4, 1887<br>M Dec. 6, 1887 |
| PAINE, SIDNEY B. | Electrical Constructor, member of firm "Paine & Francis," 38 Pearl St., Boston, Mass. | A June 8, 1887<br>M Nov. 1, 1887 |
| PARKS, C. WELLMAN | Electrician, 1825 Fifth Ave., Troy, N. Y | A July 12, 1887<br>M May 1, 1888 |

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| Name. | Address. | Date of Membership. |
|---|---|---|
| PARSHALL, H. F. | Electrician, Sprague Electric Railway & Motor Co., 16 Broad St., New York. | A Sept. 7, 1888<br>M Mar. 18, 1890 |
| PATTEN, F. JARVIS, | Electrical Engineer, 47 Barclay St., Residence, 10 West Thirtieth St, New York. | A Sept. 6, 1887<br>M Nov. 1, 1888 |
| PFANNKUCHE, GUSTAV | Engineer and Inventor, Cleveland, O. | A Feb. 7, 1888<br>M May 1, 1888 |
| PICKERNELL, F. A. | Sup't. of Equipment, Amer. Tel. & Tel. Co., 18 Cortlandt St. N. Y. | A Feb. 7, 1890<br>M Mar. 18, 1890 |
| POPE, FRANKLIN L. | (*Past President*). Expert for Westinghouse Electric Co., Elizabeth, N. J. | A April 15, 1884<br>M Oct. 21, 1884 |
| PORTER, J. F. | 403 N. 8th Street, St. Louis, Mo. | A Sept. 6, 1887<br>M Nov. 1, 1887 |
| PRATT, J. HOWARD, JR. | Professor of Physics, Jacksonville, Ill. | A June 5, 1888<br>M Sept. 7, 1888 |
| PRATT, ROBERT J. | Electrician. Manager, Electric M'f'g Co., Troy. N. Y. | A July 12, 1887<br>M Sept. 6, 1887 |
| PRESCOTT, GEO. B., JR. | (*Manager*). Electrical Engineer, General Agent, Day's Kerite Wire and Cables. 16 Dey Street. New York. | A July 12, 1887<br>M Nov. 1, 1887 |
| RAYMOND, CHAS. W.<br>* | Civil and Electrical Engineer, 36 Dearborn St., Chicago, Ill. | A June 8, 1887<br>M May 17, 1887 |
| RECKENZAUN, ANTHONY | Electrical Engineer, 7 Albert Terrace, Hemberton Road, Stockwell, London, S. W. England. | A Nov. 1, 1887<br>M Dec. 6, 1887 |
| RECKENZAUN, FREDERICK, | Electrician, Box 225, West Hoboken, N. J. | A Mar. 6, 1888<br>M June 5, 1888 |
| RICE, E. WILBUR, JR. | General Superintendent and Consulting Electrician, Thomson-Houston Elec. Co., Lynn, Mass | A Dec. 6, 1887<br>M Jan. 3, 1888 |
| RIES, ELIAS E. | Electrician and Electrical Engineer, 430 South Broadway, Baltimore, Md. | A July 12, 1887<br>M Sept. 6, 1887 |
| ROBERTS, E. P. | Electrician and Sup't, Swan Lamp Co., Belden St., Cleveland, O. | A Jan. 6, 1885<br>M Feb. 3, 1885 |
| ROHRER, ALBERT L. | Electrical Engineer, with Thomson-Houston Electric Co., Lynn, Mass. | A Nov. 1, 1887<br>M May 1, 1888 |
| SALOMONS, *Sir* DAVID LIONEL, *Bart. M. A.*, | Engineer and Barrister, Broomhill, Tunbridge Wells, Kent. and 49 Grosvenor St., London, W., England. | A Feb. 7, 1888<br>M May 1, 1888 |
| SCHLESINGER, WM. M.<br>** | Electrician of Schlesinger, Kimball & Co., Manufacturers of Electric Mining Machinery, 228 West Broad St., Columbus, O. | A Nov. 1, 1887<br>M Dec. 6, 1887 |
| SCHULZE-BERGE, FRANZ | Edison Laboratory, Orange, N. J. | A Nov. 12, 1889<br>M Mar. 18, 1890 |
| SHALLENBERGER, O. B. | Electrician, Westinghouse Electric Co., Pittsburgh, Pa. | A Sept. 7, 1888<br>M Dec. 4, 1888 |
| SHEPARD, WM. E. | Electrician, Schuyler Elec. Light Co., 25 Pratt St., Middletown, Conn. | A Feb. 7, 1890<br>M Mar. 18, 1890 |
| SLATER, HENRY B. | Electrical Engineer and Electro Metallurgist, Leadville, Col. | A April 15, 1884<br>M Dec. 9, 1884 |

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| Name. | Address. | Date of Membership. |
|---|---|---|
| SMITH, HERBERT G. | General Electrician, | A Mar. 6, 1888 |
| * | Quezaltenango, Guatémala. | M June 5, 1888 |
| STANDFORD, WILLIAM | Ass't Sup't Telegraphs, Colonial | A Oct. 4, 1887 |
| * | Gov't, Cape Town, Cape of Good Hope, Africa. | M Dec. 6, 1887 |
| STIERINGER, LUTHER | Electrical Expert, 44 Wall St., | A June 8, 1887 |
| | Room 71, New York. | M Nov, 1, 1887 |
| TERRY, CHARLES A. | Lawyer, Westinghouse Electric | A April 5, 1887 |
| | Co, Pittsburgh, Pa. | M May 17, 1887 |
| THOMPSON, EDWARD P. | Consulting Electrician and Patent | A April 15, 1884 |
| | Attorney in Electrical Cases, 5 | M Dec. 3, 1889 |
| | Beekman St., New York. | |
| THURNAUER, ERNST | Chief Engineer, Thomson-Houston | A Oct. 14, 1887 |
| | International Elec. Co, Michae- | M Dec. 6, 1887 |
| | lisbrücke, Hamburg, Germany. | |
| TROWBRIDGE, PROF. W. P. | School of Mines, Columbia Col- | A April 15, 1884 |
| | lege, New York. | M Oct. 21, 1884 |
| TURNER, WILLIAM S. | Electrical Engineer, Woodbridge | A Dec. 7, 1886 |
| | & Turner, 74 Cortlandt St., | M Oct. 2, 1888 |
| | New York. | |
| VAIL, J. H. | Electrical Engineer, Ass't to the | A June 8 1887 |
| | Pres't, Sprague Electric Railway | M Nov. 1, 1887 |
| | & Motor Co. 16 Broad St., | |
| | New York. | |
| VAN DEPOELE, CHARLES J. | Electrician, Electrical Railway | A June 5, 1888 |
| | Department, Thomson-Houston | M Sept. 7, 1888 |
| | Electric Co., Lynn, Mass. | |
| VANSIZE, WILLIAM B. | Solicitor of Patents, 44 Broadway, | A April 15, 1884 |
| | New York. | M Oct. 21, 1884 |
| WADDELL, MONTGOMERY | Engineer, 18 Columbia Heights, | A Feb. 7, 1888 |
| | Brooklyn, N. Y. | M May 1, 1888 |
| WALKER, SYDNEY F. | Electrical Engineer, 195 Severn | A June 2. 1885 |
| | Road, Cardiff, England. | M May 17, 1887 |
| WALDO, DR. LEONARD | Electrical Engineer, The Alumi- | A June 5, 1888 |
| * | num Brass & Bronze Co., Bridge- | M Dec. 4, 1888 |
| | port, Conn. | |
| WEAVER, W. D. | Assistant Engineer, U. S. N., | A May 17, 1887 |
| | New York Navy Yard. | M May 17, 1887 |
| WEEKS, EDWIN R. | General Manager, Kansas City | A Sept. 6, 1887 |
| | Electric Light Co., National | M Nov. 1, 1887 |
| | Bank of Kansas City Building. | |
| | Kansas City, Mo. | |
| WESTON, EDWARD | (*Past President* and *Vice-Presi-* | A April 15, 1884 |
| | *dent*). Electrician, 645 High | M Oct. 21, 1884 |
| | St., Newark, N. J. | |
| WETZLER, JOSEPH | (*Manager*) Editor *Electrical En-* | A April 15, 1884 |
| | *gineer*, 150 Broadway, N. Y. | M Dec. 9, 1884 |
| WHARTON, CHAS. J. | 82 Bond St., London England. | A Jan. 3, 1888 |
| | | M May 1, 1888 |
| WHEELER, SCHUYLER S., *Sc.D.* (*Manager*). | President Crocker- | |
| | Wheeler Electric Motor Co., 430- | A June 2, 1885 |
| | 432 West Fourteenth St, Elec- | M Sept. 1, 1885 |
| | trical Expert, Board of Electrical | |
| | Control, 1266 Broadway, New | |
| | York. | |
| WILKES, GILBERT | United Edison Mfg. Co., 65 5th | A Jan. 7, 1890 |
| | Avenue, New York City. | M Mar. 18, 1890 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| WILSON, FREMONT * | Electrician, 293 Lenox (6) Ave., New York. | A Mar. 6, 1888<br>M June 5, 1888 |
| WINCHESTER, A. E. | Designer of Steam Electrical Plants, Wilton, Conn. | A June 8, 1887<br>M Nov. 1, 1887 |
| WOODBRIDGE, J. L. | Electrical Engineer, Woodbridge & Turner, 74 Cortlandt St., New York, | A June 8, 1887<br>M Nov. 1, 1887 |
| ZETSCHE, DR. CARL EDUARD, | Telegraph Engineer, N. Tieckstrasse 7, Dresden, Saxony. | A Nov. 1, 1887<br>M Jan. 3, 1888 |

Members, - - - 146.

## ASSOCIATE MEMBERS.

| Name. | Address. | Date of Election. |
|---|---|---|
| ABERNETHY, J. P. | Superintendent of Telegraph, 53 City Hall, Cleveland, O. | July 7, 1884 |
| ANDERSON, ALEXANDER * | Superintendent and Manager of the Thomson-Houston Electric Co., Norfolk, Va. | Sept. 6, 1887 |
| ANDREWS, WM. S. | Supt. Construction Dept, United Edison Mfg. Co., 65 5th Ave., New York. | Mar. 5, 1889 |
| BACKSTROM, CHAS. A. | Manufacturer of Electric Incandescent Lamps, 154 & 156 West Twenty-seventh St., New York. | Nov. 13, 1888 |
| BAILLARD, E. V. | 124 West Sixty-first St, New York. | Dec. 3, 1889 |
| BARTON, ENOS M. | President Western Electric Co., 227 South Clinton St., Chicago, Ill. | July 12, 1887 |
| BARRETT, JOHN A. | Electrician, 189 Montague St., Brooklyn, N. Y. | June 8, 1887 |
| BATES, D. H. | Vice-President and Gen'l Manager, The Electrical Accumulator Co., 44 Broadway, New York. | April 15, 1884 |
| BAUER, A. H. | Electrical Engineer, Pullman Palace Car Co., Pullman Building, Chicago, Ill. Room 307. | Feb. 7, 1890 |
| BAUER, W. F. | Constructionist, The Electrical Accumulator Co., 62 Steuben St., East Orange. N. J. | April 15, 1890 |
| BAYLES, ROBERT N. | Electrician, The "C & C" Electric Motor Co., 404 Greenwich St., New York. | Oct. 1, 1889 |
| BEATTIE, JOHN, JR. | Manager and Superintendent, The Beattie Battery, Zinc and Electric Co., Fall River, Mass | Sept. 6, 1887 |
| BELDING, WARREN S. | Electrician and Sup't. The Belding Motor and Mfg. Co., 6423 Stewart Boulevard, Englewood, Ill | April 15, 1890 |
| BENBOW, WILLIAM C. | Thomson Houston Electric Co., 620 Atlantic Ave., Boston, Mass. | Dec. 3, 1889 |
| BENNETT, J. C. | Electrician, United Edison Mfg. Co. 65 5th Avenue, New York. | Mar. 18, 1890 |
| BERHGOLTZ, HERMAN | Mechanical Draughtsman, 161 East 34th St., New York City. | April 2, 1889 |
| BERLINER, EMILE | Inventor, Columbia Road, between Fourteenth and Fifteenth Sts., Washington, D. C. | April 15, 1884 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| BLACK, CHAS. N. | Student, Princeton Electrical School, Princeton, N. J. | Feb. 7, 1890 |
| BLACKWELL, R. W. | Civil and Electrical Engineer, 27 Tenth Ave., New York. | July 7, 1884 |
| BLAKE, HENRY W. | Agent, Sprague Electric Railway & Motor Co., 16 Broad St., New York. | Nov. 13, 1888 |
| BLISS, DONALD M. | Electrician, The Canada Electric Co., Amherst, N. S. | Feb. 7, 1890 |
| BLOOD, W. HENRY, JR. | Electrical Engineer, Thomson-Houston Electric Co., Lynn, Mass. | April 2, 1889 |
| BOGART, A. LIVINGSTON | Electrical and Patent Expert, 22 Union Square, New York, | July 10, 1888 |
| BOGUE, CHARLES J. | 165 West Eighteenth St., New York, | Dec. 3, 1889 |
| BOTTOMLEY, HARRY | Electrical Engineer, Thomson-Houston Electric Co., Lynn, Mass. | April 2. 1889 |
| BOYNTON, EDWARD C. | Care of Elektron M'f'g Co., 79–81 Washington St, Brooklyn, N. Y. | Aug. 6, 1889 |
| BRACKETT, PROF. CYRUS F. | Princeton, N. J. | April 15, 1889 |
| BRADY, PAUL T. | Superintendent, Central N. Y. Telephone & Telegraph Co., Cooperstown, N. Y. | July 12, 1887 |
| BRINER, C. J. | Vice-President, Central Electric Construction Co., 515 Walnut St., St. Louis, Mo. | April 2, 1889 |
| BROPHY, WILLIAM | Inspector and Electrical Expert, The New England Insurance Exchange, Boston. Residence, 51 Salem St., Worcester, Mass. | Mar. 5, 1889 |
| BROWN, ALEX. S. | General Manager, Morristown Electric Light, Heat & Power Co. Morristown. N. J. | Jan. 7, 1890 |
| BROWN, ALFRED S. | Electrical Engineer, Western Union Telegraph Co, 195 Broadway, New York City. | Mar. 18, 1890 |
| BROWN, CHARLES A. | Manager Western Electric Co., 227 South Clinton St., Chicago, Ill. | July 12, 1887 |
| BROWNING, HOWARD L. | Promoter and Contractor, 41 Dey St., New York. | Dec. 6, 1887 |
| BUCKINGHAM, CHAS. L. | Patent Attorney, Western Union Telegraph Co., 195 Broadway, New York. | April 15, 1884 |
| BURNS, ELMER Z. | Consulting Electrical Engineer, Room 55, 4th Floor. 120 Broadway, N. Y. | Feb. 7, 1890 |
| BUYS, BERT. | Electrician, Rutherford B. S. & C. Elec. Co., Rutherford, N. J. | Feb. 7, 1890 |
| CARTY, J J. | Electrician, Metropolitan Telephone and Telegraph Co., 18 Cortlandt St., New York | April 15, 1890 |
| CASE, WILLARD E. | 6 Fort St., Auburn, N. Y. | Feb. 7, 1888 |
| CHENEY, FREDERICK A. | Sec'y, Treas'r and General Manager, The Elmira Illuminating Co., Elmira, N. Y. | Oct. 1, 1889 |
| CHERMONT, ANTONIO LEITE, | Manager Telephone Co. of Para, Para, U. S. of Brazil. | Mar. 18. 1890 |
| CHILD, FRANK W. | Contractor and Builder of Electric Railways, 115 Broadway, New York. | July 10, 1888 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| CHILDS, W. H. | Bookkeeper for The Estey Organ Co., Brattleboro, Vt. | Sept. 6, 1887 |
| CHINNOCK, C. E. | Edison United M'f'g Co., 65 Fifth Ave., New York. | April 15, 1884 |
| CHUBBUCK, H. EUGENE | Electrician and Manager, Champion City Electric Light Co., Springfield, O. | Dec. 4, 1888 |
| CHURCHILL, ARTHUR. | Electrical Expert, Frazar & Co., Yokohama, Japan. | April 15, 1890 |
| CLEVELAND, WM. B. | Electrical Engineer, 309 Perry-Payne Building, Cleveland, O. | April 15, 1884 |
| COFFIN, CHAS. A. | Vice-President and Treasurer, Thomson-Houston Electric Co., 620 Atlantic Ave., Boston, Mass. | Dec. 6, 1887 |
| COLLINS, W. FORMAN ** | Western Manager, *The Electrical Engineer*, 225 Dearborn St., Chicago, Ill. | Dec. 6, 1887 |
| COMPTON, ALFRED G. | Professor of Physics, College of the City of New York, 17 Lexington Ave., New York. | Nov. 1, 1887 |
| CORNELL, CHAS. L. | Electrical Engineer, Western Engineering Co., Kearney, Neb. | Feb. 7, 1890 |
| CRANE, W F. D. | Electrician and Mechanical Engineer, The Electric Car Co. of America, Twenty-third St. and Washington Ave., Philadelphia, Pa | Feb. 7, 1888 |
| CROSBY, OSCAR T. | Electrical Engineer, Weems Electric Railway Co., Potter Building, New York. | Mar. 18, 1890 |
| CURTIS, CHAS. G. | 114 East Thirtieth St., New York. | April 15, 1884 |
| CURTISS, GEORGE F. | Electrician, Thomson-Houston Electric Co., Lynn, Mass. | April 2, 1889 |
| CUNTZ, JOHANNES H. | Assistant to Pres't Henry Morton, Stevens Institute of Technology, 137 Hudson St, Hoboken, N. J. | Mar. 5, 1889 |
| CUSHMAN, HOLBROOK | Electrical Engineer. 337 West Twenty-second St., New York. | June 5, 1888 |
| DANA, R. K. | Agent Washburn and Moen M'f'g Co., 16 Cliff St, New York. | April 15, 1884 |
| DANFORTH, A. H. ** | Great Falls, Montana. | July 12, 1887 |
| DANIELL, FRANCIS G. | Care of Minneapolis Street Railway Co., Minneapolis, Mo. | Nov. 12, 1889 |
| DAVENPORT, GEORGE W. | General Manager. Thomson-Houston International Electric Co, 620 Atlantic Ave., Boston, Mass. | June 4, 1889 |
| DAVIDSON, EDW. C. | Patent Lawyer, Room 179, Times Bldg., New York. | Feb. 7, 1890 |
| DAVIS, CHARLES H. | Consulting Electrical Engineer, 120 Broadway, New York. | Mar. 18, 1890 |
| DAVIS, CHAS. M. | Superintendent, Light, Heat & Power Co, Pueblo Col. | July 12, 1887 |
| DAVIS, DELAMORE L. | Superintendent, Salem Electric Light & Power Co., Salem, O. | April 2, 1889 |
| DAVIS, JOSEPH P. | Consulting Engineer, Care of Phœnix Construction Co., 115 W. 38th St., New York City. | April 15, 1884 |
| DAVIS, MINOR M. | Ass't Electrician. Postal Telegraph Cable Co, 5 Dey St, New York. | April 6, 1886 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| DELANY, PATRICK BERNARD, | Inventor, 84 Broad St., New York. | April 15, 1884 |
| DENTON, JAMES E.* | Professor of Experimental Mechanics, Stevens Institute of Technology, Hoboken. N. J.. | July 12, 1887 |
| DICKERSON, E. N., JR. | Attorney-at-Law, 5 Beekman St., New York. | April 15, 1884 |
| DION, ALFRED A. | Electrician, Intercolonial Railway, Moncton, N. B. | Jan. 7, 1890 |
| DOANE, S. EVERETT | Thomson-Houston Electric Co., Swampscott, Mass. | Aug. 6, 1889 |
| DOBBIE, ROBERT S. | Electrician, 1014 Bergen Ave., Jersey City, N. J. | Feb. 5, 1889 |
| DOREMUS, CHARLES A. | *M. D. Ph. D.* Chemist and Physicist, Bellevue Hospital Medical College, College of the City of New York and American Veterinary College, 92 Lexington Ave , New York. | July 7, 1884 |
| DURANT, GEO. F. | Vice-Pres't of Bell Telephone Co. of Mo., 322 Pine St., St. Louis, Mo. | April 15, 1884 |
| ELEY, HARRIS H. | Electrical Workshop Sup't. W. C. & S. W Telephone Co., 88 Colston St., Bristol, Eng. | Jan. 7, 1890 |
| ELMER, WILLIAM, JR. | Under-graduate in Electrical Engineering. Princeton University, Princeton, N. J. | Mar. 18, 1890 |
| EMMET, HERMAN L. R | Publisher and Printer, 36 Cortlandt St., New York. | April 15, 1884 |
| ENTZ, JUSTUS B. | Electrical Engineer, 18 Columbia Heights, Brooklyn, N. Y. | Jan. 7, 1890 |
| EUSTIS, HERBERT H. | President and Electrician, Eastern Electric Cable Co., 61 Hampshire St., Boston, Mass. | April 15, 1890 |
| FARMER, PROF. MOSES G. | Electrician and Inventor, Eliot, Me. | April 15, 1884 |
| FIELDING, FRANK E. | Chemist and Assayer, Virginia City, Nev. | Sept. 6, 1887 |
| FISKE, HENRY G. | Electrician, Croton Magnetic Iron Mines. 45 East Twenty-second Street, New York | Nov. 12, 1889 |
| FLACK, J. DAY | Ass't Electrician in charge of Tests, Edison Lamp Co., Harrison, N. J. | Dec. 6, 1887 |
| FLEMING, WALTER M. * * | *M. D.* Vice-President of the Averell Insulating Conduit Co., 45 Broadway, Room 1, New York. | Jan. 3, 1888 |
| FLOOD, J. F. | Electrician, Electric Light & Power Co , Steubenville, O. | Mar. 18, 1890 |
| FORD, ELLSWORTH | Superintendent Edison Electric Light Co., Ottumwa, Ia. | July 12, 1887 |
| FOX, JOHN M. | Electrician, United Edison Mfg. Co. 133 West 34th Street, New York. | Mar. 18, 1890 |
| FREEDMAN, WILLIAM H. | Honorary Fellow in Electrical Engineering, Columbia College, 120 West 125th Street, New York. | Mar. 18, 1890 |
| FULLER, LEVI K. | Vice-President, Estey Organ Co., Brattleboro, Vt. | Mar. 5, 1889 |
| GILES, WALTER A | Electrical Engineer, Mill and Mine Elec. Equipment Co. Pittsburgh, Pa. | Nov. 1, 1887 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| GILLILAND, E. T. | Vice-Pres't Empire City Elec. Co., 15 Dey St. Residence, 179 West End Ave., New York. | April 15, 1884 |
| GOLDMARK, CHAS. J. | 473 Park Ave., New York. | June 5, 1888 |
| GORTON, CHARLES | Belmont, N. Y. | Nov. 12, 1889 |
| GRAY, W. N. | Manager, Branch Office, Mather Electric Co., Cincinnati, O. | Oct. 1, 1889 |
| GROWER, GEORGE G. | Electrician and Chemist, Ansonia Brass and Copper Co., Ansonia, Conn. | Mar. 18, 1890 |
| GRIFFIN, CAPT. EUGENE | Thomson-Houston Elec. Co., 620 Atlantic Ave., Boston, Mass. | Feb. 7, 1890 |
| GUTMANN, LUDWIG | Electrical Engineer. P. O. Box 560, Pittsburgh, Pa. | Sept. 14, 1888 |
| HALL, EDWIN H. | Assistant Professor of Physics, Harvard College, 5 Avon St., Cambridge, Mass. | Sept. 3, 1889 |
| HARDING, H. McL. | Chicago, Ill. | May 24, 1887 |
| HARVEY, WIRT B. * | 43½ Madison St., Memphis, Tenn. | Dec. 6, 1887 |
| HASKINS, CARYL D. | Electrician, Thomson-Houston Electric Co., Lynn, Mass. | Mar. 18, 1890 |
| HASSON, W. F. C. | Assistant Engineer. U. S. N. Instructor Johns Hopkins University. Baltimore, Md. | Mar. 18, 1890 |
| HATZEL, J. C. | Electrical Engineer and Contractor, 29 West Twenty-sixth St., New York. | Sept. 3, 1889 |
| HALSEY, WILLIAM B. | Inspector, Postal Telegraph-Cable Co., 94 Leonard St., New York. | Mar. 18, 1890 |
| HEALY, CLARENCE L. | Sup't and Electrician, Commercial Telegram Co., 18 Broadway, New York. | April 15, 1884 |
| HEBARD, GEORGE W. | Pres't, United States Electric Light Co., 120 Broadway, New York. | April 15, 1884 |
| HENDERSON, ALBERT H. | Ries and Henderson, 45 Chamber of Commerce, Baltimore, Md. | July 12, 1887 |
| HEILMAN, DONALD B. | Jonestown, Pa. | Mar. 18, 1890 |
| HEINRICH, RICHARD O. | Demonstrator in Electrical Engineering and Physics, Lehigh University, South Bethlehem, Pa. | Oct. 1, 1889 |
| HENSHAW, FREDERICK V. | Assistant Electrician, The "C. & C." Electric Motor Co., 402 Greenwich St., New York. | Feb. 5, 1889 |
| HOCHHAUSEN, WILLIAM | Electrician, The Excelsior Electric Co., 196 Willoughby St., Brooklyn, N. Y. | April 15, 1884 |
| HOLT, MARMADUKE BURRELL, | Aspen Mining and Smelting Co., Aspen, Col. | April 15, 1890 |
| HOPKINS, J. HERBERT | 403 North 8th St., St. Louis, Mo. | April 2, 1889 |
| HOWSON, HUBERT | Patent Lawyer, 38 Park Row, New York. | June 8, 1887 |
| HUBRECHT, DR. H. F. R. | Director, Nederlandsche Bell Telephone Co., Amsterdam, Holland. | Oct. 4, 1887 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| HUMPHREYS, C. J. R. | Manager, Lawrence Gas Co., Lawrence, Mass. | Sept. 6, 1887 |
| HUTCHINSON, CARY T. | Edison Machine Works, Schenectady, N. Y. | Feb. 7, 1890 |
| IDELL, FRANK E. | Mechanical Engineer, 41 Dey St., New York. | July 12, 1887 |
| IHLDER, JOHN D. | Electrical Engineer, with Asterheld & Eickmeyer, Manuf'rs of Dynamos and Motors, Yonkers, N. Y. | Oct. 2, 1888 |
| INSULL, SAMUEL | Electrical Manufacturer, 44 Wall St., New York. | Dec. 7, 1886 |
| ISELIN, HENRY S. | President, Gibson Electric Co., 74 Cortlandt St., New York | June 2, 1885 |
| IVES, EDWARD B. | Lieutenant U. S. A., Electrical Engineer, 47 Barclay St., Residence, One hundred and thirty-ninth St. and Grand Boulevard, New York. | April 2, 1889 |
| IZARD, E. M. | Electrical Engineer, Secretary and Treas'r of the Leonard & Izard Co., The Rialto, Chicago, Ill. | Mar. 5, 1889 |
| JACKSON, C. H. | President, United Electric Light and Power Co., 59 Liberty St., New York. | May 24, 1887 |
| JACKSON, DUGALD C. | Sprague Electric Railway and Motor Co., 16 Broad St., New York. | May 3, 1887 |
| JACKSON, FRANCIS E. | With Edison Lamp Co., Harrison, N. J. | Jan. 3, 1888 |
| JAEGER, H. J. | Chemical, Physical and Electrical Glass Blowing, 173 Pearl St., Brooklyn, N. Y. | July 12, 1887 |
| JOHNSTON, W. J. | President, The W. J. Johnston Co., Ltd., Times Building, New York. | April 15, 1884 |
| JONES, SEBASTIAN C. | Electrical Engineer, Aurora, N. Y. | Sept. 6, 1887 |
| JUDSON, WM. PIERSON, | U. S. Civil Engineer, Oswego, N. Y. | June 8, 1887 |
| KENNELLY, A. E. | Electrician, Edison Laboratory, Orange, N. J. | May 1, 1888 |
| KERR, THOMAS B. | Attorney-at-Law, 32 Nassau St., New York. | Nov. 1, 1887 |
| KIMBALL, A. S. | Professor of Physics, Worcester Polytechnic Institute, Worcester, Mass. | Sept. 3, 1889 |
| KINNEY, H. A. | Representative Brush Electric Co., N. Y. Life Ins. Building. Omaha, Neb. | Mar. 18, 1890 |
| KNAPP, ALLAN C. | Electrician, 225 Dearborn St., Chicago, Ill. | Sept. 6, 1887 |
| KREIDLER, W. A. | Editor and Publisher, *Western Electrician*, 6 Lakeside Building, Chicago, Ill. | Oct. 4, 1887 |
| LAIN, DAVID E., *B. S.* | Electrical Engineer, Yonkers, N. Y. | Nov. 13, 1888 |
| LAW, M. D. | General Manager Consolidated Electric Light Co., Denver, Col. | Feb. 7, 1888 |
| LAWSON, A. J. | Electrical Engineer and Contractor, Montreal, P. Q. | Mar. 18, 1890 |
| LEDOUX, A. R. | Chemical Expert, 10 Cedar St., New York. | Dec. 7, 1886 |
| LEE, HUNTINGTON | 18 Cortlandt St., New York. | Dec. 3, 1889 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| LEE, JOHN C. | Chemist and Electrician, American Bell Telephone Co., Brookline, Mass. | Mar. 18, 1890 |
| LELAND, H. W. *** | Manager, Telephone Exchange, 259 Washington St., Jersey City, N J. | April 15, 1884 |
| LEMP, HERMANN, JR. | Electrician, Thomson Electric Welding Co., Lynn, Mass. | April 2, 1889 |
| LEWIS, HENRY FREDERICK WILLIAM. | General Manager and Secretary of the Western Counties South Wales Telephone Co., England, 16 High St, Bristol, Eng. | Mar. 5, 1889 |
| LIEBIG, GUSTAV A., JR. | Elec'l Testing Bureau, Johns Hopkins University, Baltimore, Md. | Mar. 6, 1888 |
| LOWREY, GROSVENOR P. | Lawyer, 15 Broad St., Residence 121 Madison Ave., New York. | Nov. 1, 1887 |
| LUNDELL, ROBERT | Designing Draftsman, Sprague Elec. Ry. Co., 141 East 49th St., New York. | Feb. 7, 1890 |
| MACLILIE, C. H. * | Broker in Electrical Securities, 11 Wall St., New York. | July 12, 1887 |
| MAC QUESTEN, W. D. † | Field Engineering Co., 15 Cortlandt St., New York | April 15, 1890 |
| MADDEN, O. E. | President, Empire City Electric Co., 15 Dey St., New York. | April 15, 1884 |
| MAGEE, LOUIS J. | Electrical Engineer, in charge of European Office of Thomson-Houston International Electric Co., Michaelisbrücke 1, Hamburg, Gy. | April 2, 1889 |
| MALCOLM, PHILIP S. | Western Agent, Gibson Electric Co., Portland, Oregon. | Mar. 18, 1890 |
| MANSFIELD, GEO. W. | Electrical Engineer, with Thomson-Houston Electric Co., 620 Atlantic Ave., Boston, Mass. | June 2, 1885 |
| MARTIN, T. COMMERFORD | (*Past President* and *Vice-President.*) Editor, *The Electrical Engineer*, 150 Broadway, New York. | April 15, 1884 |
| MAVER, WILLIAM, JR. | (*Manager.*) Electrical Expert, 31 Nassau St., New York. | July 12, 1887 |
| MCKIBBIN, GEORGE N. | Chemist and Electrician, 46 West Fifty-first St., New York. | June 8, 1887 |
| MCKINSTRY, J. P. | 185 Seneca St., Cleveland, O. | April 15, 1884 |
| MCMAHAN, JOHN M. † | Bergen Point, N. J. | Aug. 6, 1889 |
| MERCER, ANDREW G. | Treasurer and Electrician, Waterloo Electric Co., Waterloo, N. Y. | Sept. 3, 1889 |
| MILLER, JOSEPH A. | Civil and Consulting Engineer, Providence. R. I | Dec. 9, 1884 |
| MINER, W. M. | Electrician and Inventor, 89 East Second St., Plainfield, N. J. | July 12, 1887 |
| MITCHELL, JOHN MURRAY | Lawyer, Box 3712, 45 Wall St., New York. | June 2, 1885 |
| MITCHELL, SIDNEY Z. | Manager, Oregon, Washington and Idaho Agency, United Edison Mfg. Co., Washington Building, Portland, Or. | Nov. 12, 1889 |
| MIX, EDGAR W. | Electrician, with Thomson-Houston Electric Co., Lynn, Mass. | Sept. 3, 1889 |
| MOORE, JOHN J. | 425 E. Twenty-fourth St, New York. | Nov. 12, 1889 |
| MORRISON, J. FRANK | 15 South St., Baltimore, Md. | April 15, 1884 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| MORTON, HENRY, *Ph. D* | President of Stevens Institute of Technology, Hoboken, N. J. | May 24, 1887 |
| MOSES, DR. OTTO A. | Electrician, 131 East Seventy-third St., New York. | May 17, 1887 |
| MOSS, GEO. W. | Station Manager, C. & S. A. Tel. Co., Tehuantepec, Mexico. | Jan. 7, 1890 |
| MOSSCROP, WM. A. | Sup't of Construction, Woodbridge & Turner, N. Y., Residence, 35 Clifton Place, Brooklyn, N. Y. | May 7, 1889 |
| NEWELL, ARTHUR J, | Electrical Engineer, R. T. Oakes & Co., 184 Beech St., Holyoke, Mass. | Mar. 18, 1890 |
| NICHOLLS, F. VICTOR | Electrician and Manager Vancouver Electric Illuminating Co, Vancouver, B. C. | Dec. 4, 1888 |
| NICHOLS, ARTHUR E. | Student in Electrical Engineering, Columbia College, 16 E. 35th St., New York City. | Mar 18, 1890 |
| NUNN, RICHARD J., *M. D.* | Physician, 119 York St., Savannah Ga. | July 12, 1887 |
| OATIS, JOHN X. | Manager and Electrician, Amsterdam Electric Light & Power Co., Amsterdam, N. Y. | Sept. 7, 1888 |
| OCKERSHAUSEN, H. A. | Electrical Engineer, 65 Madison Ave., Jersey City, N. J. | Sept. 6, 1887 |
| O'DEA, M. | Electrician, University of Notre Dame, Notre Dame, Ind. | June 8, 1887 |
| PALMER, G W., JR. | General Manager, McKeesport Light Co, McKeesport, Pa. | April 15, 1890 |
| PARSELL, HENRY V., JR. | 31 East Twenty-first St., New York. | Nov. 12, 1889 |
| PAUL, CHAS. M. | Electrician, Care of Weston Electrical Instrument Co., 645 High St., Newark, N. J. | May 7, 1889 |
| PECK, SAMUEL C. | Electrician, Thomson-Houston Electric Co., 620 Atlantic Ave, Boston, Mass. | Sept. 6, 1887 |
| PEIRCE, WM. H. | Superintendent Marine Installations, United Edison M'f'g Co., 65 Fifth Ave., New York. | Sept. 7, 1888 |
| PHELPS, GEO. M. | (*Treasurer*). Electrical Engineer and Editor, 150 Broadway, New York. | April 15, 1884 |
| PHILLIPS, EUGENE F. | M'f'r Insulated Electric Wire, Providence, R. I. | July 13, 1889 |
| PLUSH, DR. S. M. | Electrician, 319 South Tenth St, Philadelphia, Pa. | April 15, 1884 |
| POOLE, CECIL P. | Contracting Electrical Engineer, 206–8 Eighth St. Lynchburg, Va. | Jan. 3, 1888 |
| PUPIN, MICHAEL I. | Instructor in Mathematical Physics, Columbia College, 68 W. 72d St., New York City. | Mar. 18, 1890 |
| POPE, RALPH W. | Secretary of the American Institute of Electrical Engineers, 5 Beekman St., New York. | June 2, 1885 |
| RAE, FRANK B. | Electrical Engineer, Detroit Electrical Works, Detroit, Mich. | April 15, 1884 |
| RANDALL, JOHN E. | Incandescent Lamp Dep't, Thomson-Houston Electric Co., Lynn, Mass. | May 7, 1889 |
| REED, CHAS. J. | Electrician, 224 High St., Orange, N. J. | Mar. 5, 1889 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| REED, HENRY A. | Secretary and Manager, Bishop Gutta-Percha Co., 422 East Twenty-fifth St., New York. | June 4, 1889 |
| REILLY, JOHN C. | General Sup't, N.Y. & N. J. Tel. Co, 16 Smith St, Brooklyn, N. Y. | April 15, 1884 |
| REINMANN, A. L. | Electrician, Breckenridge Ave., Pittsburgh, Pa. | June 8, 1887 |
| RIKER, ANDREW L. | Electrical Engineer. 15 East Fifty-fifth St., New York. | Nov. 1, 1887 |
| ROBINSON, ALMON, | Draughtsman, Expert in Methods of Gearing, P. O. Box, 943, Lewiston, Me. | Sept. 6, 1887 |
| ROEBLING, FERDINAND W. | Manufacturer of Electrical Wires and Cables. Trenton, N. J. | June 8, 1887 |
| ROESSLER, S. W. | Captain, U. S. A., Willet's Point, Whitestone, N. Y. | |
| ROGERS, WINFIELD S. | Mechanical Engineer, Watervliet Arsenal, West Troy, N. Y. | Sept. 3, 1889 |
| ROOME, H. C. | 32 Liberty St., New York. | April 15, 1889 |
| ROSENBAUM, WM. A. | Electrical and Patent Solicitor, Care of *The Electrical World*, Times Building, New York. | Jan. 3, 1889 |
| ROYCE, FRED W. | Electrician and Patent Solicitor, 1408 Pennsylvania Ave., Washington D. C. | April 15, 1884 |
| RYAN, HARRIS J. | Professor of Electrical Engineering, Cornell University, Ithaca, N. Y. | Oct. 4, 1887 |
| SARGENT, W. D. | General Manager, N. Y. & N. J. Tel. Co., 16 Smith St., Brooklyn, N. Y. | April 15, 1884 |
| SAWYER, FREDERICK J. | Pres't, The New England Electric Co., 55 Oliver St., Boston, Mass. | June 8, 1887 |
| SAXELBY, FREDERICK, | Electrical Engineer, Superintendent of Exhausting Department, Edison Lamp Co., Harrison, N. J. | June 5, 1888. |
| SCHMIDT, FREDERICK, | Managing Director, The Schmidt-Douglas Electric Co., L'td., 31 Blenheim Rd., Bradford, England. | Jan. 3, 1888 |
| SEARING, LEWIS | Care A. S. Pope, Box 124. Colorado Springs, Colorado. | April 3, 1888 |
| SEELY, J. A. | General Manager, Complete Construction Co., 24 Cortlandt St., New York. | April 15, 1884 |
| SERRELL, LEMUEL WM. | Mechanical and Electrical Engineer, 115 Broadway, New York. | Nov. 1, 1887 |
| SHAW, GEORGE B. | General Manager, National Electric Mfg. Co., Eau Claire, Wis | April 15, 1890 |
| SHEEHAN, WILLIAM M. | Manager and Electrician, Newburgh Electric Light & Power Co., 65 Montgomery St., Newburgh, N.Y. | Sept. 3, 1889 |
| SISE, CHARLES F. | Vice-President and Managing Director, Bell Telephone Co., of Canada, and Canadian Telephone Co., Ltd., Montreal, Canada. | June 8, 1887 |
| SMITH, FREDERICK H. | Civil Engineer. 227 East German St., Baltimore, Md. | Nov. 12, 1889 |
| SMITH, GERRITT | Circuit Electrician, 195 Broadway, New York. | April 15, 1884 |

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|---|---|---|
| SMITH, J. ELLIOT | Superintendent Fire Alarm Telegraph, 157 East Sixty-seventh St., New York. | April 15, 1880 |
| SMITH, JESSE M. | Consulting Electrical Engineer and Expert in Patent Causes, 36 Moffatt Block, Detroit, Mich. | April 15, 1884 |
| SOUZA, CARLOS MONTEIRO e | Rio de Janeiro, Brazil. | Sept. 6, 1887 |
| SPICER, CHAS. W. W. | 122 West 21st. St , New York City. | Nov. 12, 1889 |
| SPIKE, CLARENCE J. | Halifax, N. S. | Mar. 18, 1890 |
| SPRAGUE, FRANK J. | Electrician, and Vice-President, Sprague Electric Railway & Motor Co., 16 Broad St., New York. | May 24, 1887 |
| STADELMAN, WM. A. | Vice-Prest. and Chief Engineer, Equitable Elec. Ry. Construction Co., 418 Walnut St , Philadelphia, Pa. | Feb. 7, 1890 |
| STANLEY, WILLIAM, JR. | Electrician, Englewood, N. J. | Dec. 6, 1887 |
| STEARNS, CHARLES K. | With Thomson-Houston Electric Co., 620 Atlantic Ave., Boston, Mass. | Aug. 6, 1889 |
| STEBBINS, THEODORE | Electric Railway Inspector, Thomson-Houston Elec. Co , 620 Atlantic Ave., Boston, Mass. | July 9, 1889 |
| STEINMETZ, CHARLES | Electrician, Osterheld & Eickemeyer, Yonkers, N. Y. | Mar. 18, 1890 |
| STOCKBRIDGE, GEO. H. | Patent Attorney, 132 Nassau St., New York. | May 24, 1887 |
| STOCKLY, GEO. W. | President, Brush Electric Co., Cleveland, O. . | April 15, 1884 |
| STUART, OTIS K. | Clerk, Thomson Electric Welding Co., Lynn, Mass. | June 4, 1889 |
| STUMP, CLARENCE E. | Bus. M'g'r and Treas'r, The W. J. Johnston Co., Ltd., Publishers of the *Electrical World*, 167–177 Times Building, New York. | May 17, 1887 |
| TAYLOR, CHARLES | Metallurgist. U. S. Assay Office, 30 Wall St., New York. | Nov. 1, 1887 |
| TEMPLE, WILLIAM CHASE | Electrical Engineer, 575 Madison Ave., New York. | May 3, 1887 |
| TESLA, NIKOLA | Electrical Engineer and Inventor, Astor House, New York. | June 5, 1888 |
| THOMPSON, WILLIAM GEO. | MACNEILL, Resident Engineer, Sault Ste Marie Canal, Sault Ste. Marie, Ontario. | July 12, 1887 |
| THOMSON, PROF. ELIHU | (*President*). Electrician, Thomson-Houston Electric Co., and Thomson Electric Welding Co., Lynn, Mass. | April 15, 1884 |
| TOWNSEND, HENRY C. | (*Manager*). Attorney and Expert in Electrical Cases, 5 Beekman St., New York. | July 10, 1888 |
| TREGONING, JOHN | Sup't, Thomson Electric Welding Co., 325 Boston St., Lynn, Mass. | April 2, 1889 |
| UEBELACKER, CHAS. F. | Student, Princeton Electrical School. Princeton, N. J. | Feb. 7, 1890 |
| UHLENHAUT, FRITZ, JR. | Field Engineering Co., 15 Cortlandt St., New York. | May 7, 1889 |

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|---|---|---|
| UPTON, FRANCIS R. | (*Vice-President*). Treasurer and General Manager, Edison Lamp Co., Harrison, N. J. | May 17, 1887 |
| VAIL, THEO. N. | President, Metropolitan Telephone & Telegraph Co., 18 Cortlandt St, New York. | April 15, 1884 |
| VARLEY, RICHARD, JR. | Electrician, Okonite Insulated Wire Co., Passaic, N. J. | Mar. 18, 1890 |
| VAN BRUNT, WALTER | Manager, Duluth Telephone Co., Duluth, Minn. | Sept. 6, 1887 |
| VANCE, A. ST. CLAIR | 65 Fifth Avenue, New York. | April 2, 1889 |
| VAN TRUMP, C. REGINALD | Wilmington City Electric Co., Wilmington, Del. | Feb. 5, 1889 |
| VAN VALKENBURGH, F. S. | Central and South American Tel. Co., Tehuantepec, Mexico. | June 5, 1886 |
| VAN VLECK, FRANK | Chief Engineer, San Diego Cable Tramway Co., San Diego, Cal. | Nov. 16, 1886 |
| VIDUARRE, JOSE | Dealer in Electrical Supplies, Ponce, Porto Rico. | Sept. 6, 1887 |
| WACKER, GEORGE G. | Electric Organs, 3644 Third Ave., New York. | Sept. 6, 1887 |
| WALLACE, WILLIAM | Wire Manufacturer, Ansonia, Conn. | April 15, 1884 |
| WALTER, HENRY E. | Schenectady, N. Y. | April 2, 1889 |
| WARDELL, GEORGE P. | 19 Cedar St., Newark, N. J. | Nov. 12, 1889 |
| WARING, RICHARD S. | 205 Penn Building, Pittsburgh, Pa. | April 15. 1884 |
| WATERHOUSE, FRANK G. | Ass't General Sup't,' Westinghouse Electric Co., Pittsburgh, Pa. | Sept. 6, 1887 |
| WATERS, EDWARD G. | Electrical Engineer. Thomson-Houston Electric Co , 620 Atlantic Ave., Boston, Mass. | Mar. 18. 1890 |
| WEIL, LEOPOLD | Importer, 121 Mercer St., New York. | June 8, 1887 |
| WELLES, FRANCIS R, | Manufacturer, Bell Telephone Manufacturing Co., Antwerp, Belgium | Sept. 6, 1887 |
| WHITE, H. C. | Manager, Phœnix Iron Works Co., 16 Dey St., New York. | April 15, 1884 |
| WHITE, J. G. | Manager, The Western Engineering Co., Kearney, Neb. | April 2, 1889 |
| WHITE, WILL F. | Electrical Engineer, Sec'y and Treas. Western Engineering Co., Kearney, Neb. | Feb. 7, 1890 |
| WHITMORE, W. G. | Electrical Engineer, United Edison Mfg. Co., 65 Fifth Ave., N. Y. C. | Mar. 18, 1890 |
| WHITNEY, HENRY M. | President, West End Street Railway Co., 81 Milk St., Boston, Mass. | July 12, 1887 |
| WIGHTMAN, MERLE J. | Electrical Engineer and Inventor, Thomson-Houston Electric Co., Lynn, Mass. | Mar. 5, 1889 |
| WILEY, WM. H. | Scientific Expert, 15 Astor Place, New York. | Feb. 7, 1888 |
| WILLIAMS, CHARLES, JR. | Electrician, 100 Sudbury St., Boston, Mass. | April 15, 1884 |
| WILLIAMS, JAMES B. *M. D.* | 44 Broadway, New York. | Sept. 7, 1888 |
| WINKLER, CHARLES F. | Electrician, Troy Electric Dynamo Co., 4 Park Ave., Troy, N. Y. | Sept. 3, 1889 |
| WINSLOW, I. E. | 458 Produce Exchange, New York. | Nov. 12, 1889 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| WINTRINGHAM, J. P. | Theorist, 36 Pine St., New York. | May 7, 1889 |
| WIRT, CHARLES. | United Edison Mfg. Co., 65 5th Ave., New York. | Sept. 8, 1888 |
| WOLCOTT, TOWNSEND | Consulting Electrician, 849 Greene Ave., Brooklyn, N. Y. | Mar. 6, 1888 |
| WOLVERTON, B C. | Electrician, N. Y. & Pa. Telephone & Telegraph Co., Elmira, N. Y. | Mar. 18, 1890 |
| WOOD, E. J. | Consulting Engineer and Contractor, 243 Broadway, New York. | July 12, 1887 |
| WOODRUFF, H. O. | Agent, Sprague Electric Railway & Motor Co., Des Moines, Iowa. | Oct. 2, 1888 |
| WORTHINGTON, GEORGE | Manager, *Electrical Review*, 13 Park Row, New York | April 15, 1884 |
| YOUNG, ALDEN M. | Contractor for Organization and complete Equipment of Electric Lighting Plants, 101 Bank St., Waterbury, Conn. | Sept. 6, 1887 |
| YOUNG, C. GRIFFITH | Superintendent and Electrician, Mount Morris Electric Co., Vandam and Greenwich Sts. Residence, 262 West One hundred and twenty-third St., New York. | Jan. 3, 1889 |
| ZALINSKI, EDMUND L. | Captain of Artillery, U. S. A., Care of War Dept., Washington, D. C. | May 17, 1887 |

Associate Members, - - - 280.

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SUMMARY.

| | |
|---|---|
| Honorary Members, - - - - - - - - - | 2 |
| Members, - - - - - - - - - - | 145 |
| Associate Members. - - - - - - - - - | 280 |
| Total - - - - | 427 |

Any errors in this list, or changes in address should be reported to the Secretary.

OTHO ERNEST MICHAELIS, Ph. D., Major of Ordnance, U. S. Army, and Commandant of the Kennebec Arsenal, Augusta, Me., died at Augusta, of spinal menginitis, May 1st, 1890. Major Michaelis—then Captain—was elected an Associate Member of the Institute December 9th, 1884, and was transferred to full membership, January 6th, 1885. On May 18th, 1886 he was elected a Manager, and upon the expiration of his term was elected a Vice-President May 21st, 1889, which office he held at the date of his death. He was 46 years of age.

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# AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

The forty-fifth meeting of the Institute was held at Columbia College, New York City, April 2d, President Seth Low, of Columbia College, in the chair, who welcomed the Institute with the following address:—

PROFESSOR THOMSON AND GENTLEMEN OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS: It is a very great pleasure to me, as President of Columbia College, to welcome you to our buildings this evening. You remember that at the Philadelphia Exposition of 1876, over the portals of the Egyptian Department was an inscription something to this effect, "Earth's Oldest Nation to her Youngest, Greeting." And so it seems a very fitting thing that the oldest educational institution, certainly of a high order, in New York City, should give this welcome to representatives of the youngest of the sciences. (Applause.) I can assure you that you could go to no place on this Continent where you would receive a happier or more sympathetic or more intelligent welcome; for there is this difference between old Egypt and old Columbia—whereas the greatness of Egypt lies in her past, those of us who are working in Columbia to day are sanguine with the expectation that what Columbia has been and done in the past is only the earnest of what she will be and do for science, for all education, in the coming time. (Applause.) And that which we think of Columbia we think of you, and that which the electrician has done in the past is only the earnest of what he yet shall do. I rather expect to see the day when this little Electrical School here, which has just been started under the auspices of Columbia, may need a building larger than any one we have upon this block for the proper execution of its work and for the proper care of its collections. And this is to be thought of and remembered by you who come to us from a distance, that whereas some colleges have given their attention to science out of funds specifically donated for that purpose, all that Columbia has done through her School of Mines and its many-sided activity, she has done out of the general purse. She has recognized that valuable as letters are, valuable as the classics and philosophy are, science is equally entitled to her care. As men of science I suppose that is all you will ask. Again I welcome you very cordially, Mr. President and all your colleagues, to Columbia College.

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*A lecture delivered at the 45th meeting of the American Institute of Electrical Engineers. New York, April 2, 1890.*

# PHENOMENA OF ALTERNATING CURRENT INDUCTION.

BY PROFESSOR ELIHU THOMSON.

MR. PRESIDENT, LADIES AND GENTLEMEN, AND MEMBERS OF THE INSTITUTE: The subject which we have in hand this evening is more of an experimental character than otherwise, and the object is to bring before the Institute chiefly the results of some actions in relation to alternating currents—actions which are novel and curious, and some of which have never before been shown to the public. Others formed the feature of the exhibit which we made at Paris in the past year. The lecture will deal chiefly with effects producible in closed conductors or closed bands subject to the influence of what we call induction. Everyone is familiar with the action produced by passing a current around a bar of iron. If we have a coil surrounding the bar and pass an ordinary continuous current, as it is termed —a current which does not change its direction and does not vary greatly, we get, according to the direction of the current, north and south polarity respectively developed at the ends of the bar and down the sides to some extent, the neutral region or point of no polarity being in a bar of uniform section and of uniform material about the centre. I may say that the magnetization in putting the current through the coil is almost instantaneous, that is to say, if the magnet is of moderate dimensions and we connect it with a battery, we find at once that the ends are north and south in polarity. But if we take such a magnet and surround it with a thick copper tube, or, what will answer just as well, a band of copper, which makes what we call a closed circuit, then we find that on passing the current into the inner coil, for example, the magnetism does not appear instantaneously at the ends, but we have it coming very lazily and

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gradually, according to the thickness of this outer envelope of copper. We make what is called a sluggish magnet. We slow up the production of magnetism in the bar. The reason for this is very simple. When we start the current through the inner coil we have at the same moment a reverse or opposing current passing in the outer coil or band which kills or holds back the development of magnetism. After a little while, it may be a second or two in moderate-sized magnets, sometimes even more than that—the magnetism has reached about its normal value as though no band or closed circuit surrounded it. We can in this way construct magnets which will not respond to quick impulses of current, but will only respond to impulses lasting for a certain time. These are facts which are pretty well known and sometimes made use of. But let us now consider what would happen if we were to take away the continuous current and substitute what we call an alternating current—a current which goes in one direction during a portion of the time and reverses, going in the other direction, during another portion of the time. These currents can be made to change their direction many thousand times a second, or we can have them change only a few times a second, or have them change every few seconds. The period or rapidity of vibration or alteration can be varied within the widest limits We find that with the alternating current passed through the coil—removing the envelope—we will get north and south polarity quickly reversed. That is, every time one current moves one way through the coil, north magnetism will appear at one end of the bar and south magnetism at the other, and when it reverses, the magnetism will reverse, and if the current alternates or changes its direction many times a second, these alternations of magnetism will produce what we call an alternating magnetic field outside of the bar. At the same time we will notice that the alternating current is strongly opposed in its passage by having to reverse the magnetism. That is, it is doing the work of upsetting or turning around the particles of iron in the bar and it encounters an opposition. The poles will reverse rapidly, as I was saying, and we will have magnetism developed, but we will not be able to tell whether it is north or south if the alternating current is changing its course rapidly; but we will find, as I said, that the alternating current will not pass as freely through the coil as a continuous current, but will meet with an opposition which we

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call self-induction—or counter-electromotive force. Now, if we put the closed band in place around the coil we will find that the magnetic effects are almost wiped out, and further that the opposition to the passage of the currents through the coil has been almost exterminated. Or, in other words, the coil has now become transparent to the alternations—the alternations passing freely through, whereas before they were very much hindered. Here then, we have another difference from the action which takes place with continuous currents. Furthermore, we find that if this band is loose or movable we will get mechanical actions exerted with the band in certain positions We make use of these principles in what are called re-active coils for alternating currents, an example of which is found here, (Fig. 1.) If we pass through the coil which you see wound upon this structure, or core made of sheet iron—if we pass a current through this coil, we find that when this copper piece which forms a band around the coil, is over here away from the coil a very great opposition is exerted to the passage of the alternating current, and we can use that coil in order to oppose the passage of such currents just as we would put a resistance in circuit with a continuous current to oppose its passage—with this difference, that wherever we use a resistance in circuit with a continuous current we lose the energy of the current—we waste current; but in the case of the use of such a coil as this—a self-inductive coil—we waste only a small amount of the energy and are enabled to oppose the passage of the alternating current or currents with great force—cut it down without making the loss real.

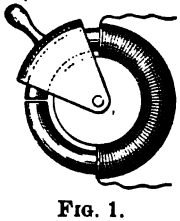

FIG. 1.

If now we wish to remove that opposing influence we can do it with the greatest possible smoothness by simply bringing this closed copper band over the coil and we can graduate in that way to the nicest degree possible the force of the alternating current subject to this action. But we would notice, in using the apparatus for the purpose mentioned, that, when we began to bring this copper over the other coil, an opposition to the movement—we would find a repulsion—a tendency to drive back or remove the copper. In fact we can easily imagine that with the copper band in the present position a strong current sent through the terminals of the apparatus would throw it completely over so as to put the full kick or reaction in the

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circuit. This repulsive action is one of the phenomena to which I wish to call attention particularly this evening. That is, we propose to make this outer band loose—to give it a chance to move and then study some of the actions obtained. I brought to the notice of the Institute about three years ago a variety of dispositions of parts, apparatus and devices showing this repulsive action, and I explained it, but we had not then the opportunity for actually bringing to the notice of the members the instances of the experimental action of the devices—the devices were not at hand, the current was not at hand, and it was not easy to arrange matters. But we will now make up for that, or try to. Now it is hardly worth while this evening to go into a full discussion of the causes of this repulsion. I will state it very briefly, and it will be a repetition of what has already been said before the Institute. It is simply this—the cause of the repulsion is that in this outer band there will be developed during the passage of the alternating impulses through the inner or inducing coil, currents which are opposite in direction throughout the major part of their time of existence to those which produce them. If we could imagine a current passed through this inner coil producing what may be called the theoretical effect purely, there would be no such repulsion. But there comes into play an action which we call the lag or retardation of the impulse. This action disturbs the opposition of the waves in such a manner as to cause the current produced in the outer band by induction to be opposite in direction to the currents which produce the induction; and opposite currents, according to the laws well known, are repellant; so that if we have two conductors near together, in which opposite currents are flowing, we have a repulsive effort exerted. We ought to get, according to theoretical considerations, and without introducing any consideration of displacement of currents from the theoretical position—a wave which is just a quarter of the wave length back of the wave which induces it. But in actual practice, if we use as the closed band a conductor of considerable size, and of good conducting material, this wave is not so produced; but it is moved, it is shifted to this position, (illustrating); that is, our real wave is not the one the quarter wave displaced, but we find it nearly where I now show it. That is, the current in one coil is in one direction, the current in the other coil is in the opposite direction, and this produces a repulsive

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effort. I do not propose to go much further into the consideration of that subject, because we have a number of phenomena to bring before you and that matter has already been discussed before the Institute.[1]

One of the earliest experiments which I happened to make as showing somewhat similar action to that just mentioned, was to take a coil of wire provided with an iron core; and support a disc of copper, in a balanced way, in front of it, keeping it properly balanced by counterpoises. We will carefully adjust the weight so as to get it to about a balanced condition. On passing a continuous current through this coil, we simply magnetize the iron inside the coil. We produce suddenly a north pole at this point, but that sudden production of a north pole induces currents in the disc placed opposite to the pole which flow in such directions as to produce a north pole, as it were, pointing downward, so that these two north poles repel each other. If, on the other hand the disc were slightly lifted, and I cut off the current, the disc will at once fall; but if I repeat the operation of putting on the current and taking it off quickly, we find that there is a continued repulsion; or in other words, the disc is kept at a distance from the core. The disc now is down and I will put on the current and you will see it rises about half an inch and is now in oscillation. I tried this experiment about five years ago. You see that every time I put on the current there is a repulsion upward of the disc. If now I quickly make and break the circuit you will see that the disc will stand at a distance. It is thrown off the core. We have, in other words, a repulsion produced by continuous currents quickly interrupted. That is due to the fact that the currents induced or set up by the production of a magnetic pole in this core are attended by the production of other currents in the disc, which oppose the action and drive the disc away. (Fig. 2.)

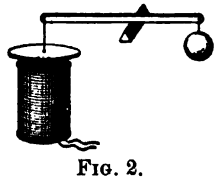

FIG. 2.

Alternating currents applied to the same conditions may be regarded as very much more rapidly interrupted, and, at the same time, reversed currents, and consequently the magnetic effects are very decided. To show the action with alternating

1. See "Novel Phenomena of Alternating Currents," p. 100, Vol. iv. of Transactions.

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currents, we have only to take a plain copper ring and lay it over the coil as you see. (Fig. 3.) We have a source of alternating currents which are conducted from the lines outside, and which are transformed by a transformer to 200 volts, beginning at a thousand volts on the supply lines, and I will close the circuit of the secondary coil, and you see that we have a copper ring resting on a support some distance down the inducing coil. You see this action of repulsion is so considerable as to throw the ring bodily upward. (Applause.) Here the action is exactly what we have before seen, but it is intensified to a wonderful extent. This is a heavy, solid, copper ring, and it is driven, as you see, up into the air quite a height. If I put on the current now for a few moments permanently, I may be able, with care, to balance this ring for an instant in free air. (Applause.) This action of repulsion may be exhibited in very many ways, and, as you see, we have one here, in which instead of holding the ring it is now supported in the air. But that is not all—two rings are as well supported as one.

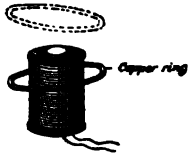

FIG. 3.

The reason for this is quite simple. That ring is affected by the alternating current passing in the inducing coil and it is affected in such a way as to produce currents that circulate reversely, but are always behind time as respects the inducing currents so as to be in the opposite direction to these currents at nearly all times. This second ring put under the same conditions is affected in precisely the same way as that ring, and therefore the currents in that ring and in this ring are parallel and in the same direction. Consequently they attract each other instead of repelling. We have then repulsion from this first band and the coil—between this second band and the coil, and because the one is affected like the other, we have attraction between them so that they hang together, and you can hear the tremor of the alternations. That little rattle you hear indicates simply the time when there is no current. The rings fall apart for a moment and before they can get apart another current is set up which draws them together. (Fig. 3*a*.)

FIG. 3*a*.

Not only is this repulsive effect manifested as you see, but if the ring cannot get away from the coil it will undergo what we call the deflective action, or it tends to turn up; besides the ac-

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tion is exerted all around the coil as you see. I cannot bring that ring over the coil. It is thrown back. Wherever there is any of this magnetic field the repulsion is exerted and it tends to turn the ring up into the vertical position or plane. The moment I turn it down in this fashion, you see it is with difficulty that I can pass it over the coil. But if we desired to cut off all this effect we would only need to cap that coil with a very heavy copper cap, and then the experiments would take on a very different character. I cannot lay this copper plate on the coil, as you see. This acts just as the ring does. It is a number of rings concentric, all of which can have current developed in them, and it is impossible to lay this plate on the coil, for it is driven away. If I were to cut the current off and lay the ring down, and then put on the current in the inducing coil, the copper disc would jump off. That is the case, too, with a silver coin if we get the field strong enough. There is hardly force enough there; but if we get a very powerful field a silver coin will be thrown completely off. This disc we may say exhausts the magnetic field. If I lay it in the field and force it down I get an effect preventing the passage of magnetic force through it. Here is a lamp which I light simply by connecting it with a coil and bringing the coil near this coil or pole Notice when I put the copper plate between. Now we will insert the copper plate—the lamp is extinguished. And the moment we withdraw the plate it lights again, and we can can graduate its intensity, and as it were turn the lamp up and down as we do with gas. (Fig. 4.) I call this a shading action—that is, the plate shades the magnetic field. Or it may be said to be a deflector—it deflects or reflects the magnetic field. It is like a polished plate of silver as compared with light, and we have only to bring it down to the field and we find that the field is diverted and kept from passing through, so that it cannot affect the coil on the upper side which would feed the lamp if the field were not shaded.

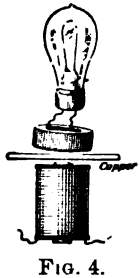

FIG. 4.

We could vary these experiments to a great extent, and I had prepared a few examples of variation, but one of them met with an accident—that was this little floating lamp. This little lamp ought to be connected with the coil, but it got broken on the way, and therefore I cannot show the experiment. It was to be placed in this glass vessel full of water, and, as you see, it would fall to the bottom. If the circuit had been complete, on putting it into the field, we would not only see the lamp

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light under the water by the sheer effect of the magnetic field traversing the water and producing light in the lamp, but we would also see at the same time the lamp rise, and we would have both phenomena—the production of current, demonstrating that the action is due to current developed in the coil because the current lights the lamp, and we would also have the repulsive action of the current. It is a very pretty experiment, and I am sorry it has been prevented by this accident.

There is another point, however, I cannot leave out in connection with it, namely, that we might have the coil floating in the liquid at a certain height as repelled, and then by diminishing the current here in the inducing coil we would find that instead of having the lamp changing its brilliancy it would simply settle down and remain of the same brilliancy as before; that is, the repulsive effort would become less. It would drop to a position where the repulsive effort was as much as before, and then the lamp would have the same brilliancy. We have, as it were, an automatic regulator for the lamp by which, no matter how the current varies, we can have a standard illumination. (Fig. 5.)

FIG. 5.

But fortunately I have arranged to show this in a different way. I have a lamp and coil which are placed on the end of a lever. This gets rid of the liquid and gives us a means of balancing the lamp at any brilliancy we desire. I there place the little lamp on the lever, put counterpoising weights on the other side, and you see it floats or is balanced at a distance from the coil. But if the inducing current were slightly diminished, we would find that the lamp would settle down. In fact, it does always rise and fall a little from the variations on the circuit. I may set that lamp then to burn at a certain brilliancy and if I wish to vary the brilliancy I take off a weight from the counterpoise and it rises in brilliancy. If I add more weight to this side I would, of course, diminish the brilliancy, and it might remain balanced under these still new conditions. I take off several of the counterpoise weights. There we have considerable increased brilliancy given, and the lamp will remain so, no matter whether the current fluctuates or not, providing we

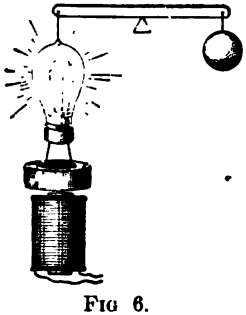

FIG 6.

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always have a space between the coils, which will enable it to go and come and preserve its proper brilliancy. (Fig. 6.)

It will readily be seen from what we have shown that we have a mechanical effort exerted tending to drive away this closed conductor. We could easily use that mechanical effort to produce a movement from alternating currents. We can in fact use it to produce a rotary motor which turns continuously by simply being supplied with an alternating current. We can use it in the measurement of alternating currents. It has been applied to meters, to regulators, to motors, and in various ways. But it is not my purpose to go into the details of its application this evening, as we have much other matter which will take up the time. I would simply say that motors have been made which run with considerable power, and which appear to have a fair efficiency, and at the same time are self-starting—based on the principle of simply closing a circuit when it is in the proper relation to the alternating current coil, allowing it to be repelled to a distance away, then closing another circuit, and so on, making what is called the transformer type of alternating current motor. Now, we have come to another department of the subject growing out of the experiments which I showed with this ring and the other ring. I have shown that if one ring be placed over the coil and another ring be brought under it there is a tendency to attraction. An attraction is exerted which brings the one ring directly over the other ring. Evidently we could use this principle also as a source of motion, because these two parallel currents may be made to attract each other, but the limit of the movement is at once found. When the rings are parallel substantially, they cannot move farther—they cannot get any nearer than when they touch. But we can so modify these effects as to produce a continuous rotation, and I will show a few instances of that. I may take a copper disc mounted on pivots and this copper ring. I place the ring here over the coil and the pivoted disc alongside. Perhaps I can work it at an angle so that the effect may be better seen. (Fig. 7). It occurs with greater vigor in this position; the revolution becomes very rapid. I have only then to put this closed circuit ring over the other or inducing coil; modify the field by placing it there, and then put this rotating disc in front of the magnet there, above or below

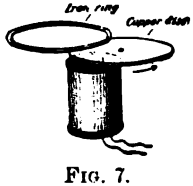

FIG. 7.

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the ring—it doesn't matter which—if I put it above I get the effects of rotation, and if I put it below I get the same effects precisely—either one side or the other this ring may go, and the disc is set into rotation. This disc is in essence nothing more than a series of rings which can be thrown into parallelism or attempted parallelism with the first ring or band and then finding new material to one side and which has not got into parallelism, a renewal of the action goes on and results in rotation of the disc. But I wish to call attention to one fact, that if I put the ring exactly concentric with the inducing coil I do not get such effects; I must displace it laterally. No movement occurs if I place it exactly concentric—it is difficult to find that point in this case—and if I err ever so little, the disc begins to revolve. If I carry it over to the other side the disc revolves in the other direction. The effect is very easily obtained also by substituting for the ring a plate of copper. (Fig. 8.) That is, the plate is virtually a ring or a set of rings, as well as the disc, and if I place this sheet of copper in front of the pole the actions are the same as before, and if I wish to reverse the action I place it on the other side. In fact any closed circuit that I may make or bring into position in this field will so modify the field that the disc will be set in motion. It is not necessary at all that we use a copper disc. We may use an iron disc, but then we will notice something quite different. The iron disc is vigorously attracted, and we have to be careful not to let it be pulled down. You see the iron disc is now in rapid rotation in the same way, and is reversed in the same manner as with the copper disc, but there is a real difference between iron and copper in this connection, as we will see. I will put this copper disc here vertically to the ring. Now it has come to rest in a balanced position. It does not rotate, but it does rotate if I put it down in this position, parallel with the field modifying ring. Let us take the iron instead and there is no trouble about the iron in the vertical position. Hence you see we have really a difference after all. The copper and iron do work alike, but they do not work alike altogether. Now the fact is that we have come to deal with two different phenomena in these cases. This copper works when it is parallel with the plate or closed ring because its action depends on the circulation of currents in the plane of the

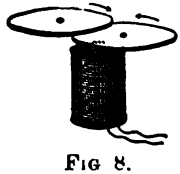

FIG 8.

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disc, which cause it to rotate. The iron will work just as well one way as the other way, and at all angles, because it does not depend for its action upon currents that are set up in the iron, but simply on the property which iron has of not changing its magnetism until it is forced to. That is, it has the property sometimes called by the term magnetic friction—magnetic lag, or the more modern term "hysteresis." It is not exactly like air in its magnetic capacity. It has, in other words, a tendency to remain magnetized as it was, and so resists change when we place it in a field which forces it to change. We place it in front of a pole which does not remain north or south, but which is constantly changing from north and south and at the rate of about 250 times a second of change. Hence, if the lower part of the iron disc gets magnetized north and the top becomes south, instantly, if this disc cannot accept the new condition of reversed poles from the core below with great readiness, it is evident that the polar part of the disc wants to leave, and the new portion, which has not been given a magnetic polarity, will tend to be brought into play instead. But when we place the disc over the inducing coil or core in this manner in a vertical plane, it simply oscillates a little and comes to rest. It does not know which way to turn. It might just as well go out one way as the other, but now this ring or closed circuit decides the question. The copper plate decides that the iron shall move in one certain direction. Now, we may analyze this action a little on the blackboard, because here we shall find a key to all these aetions. We will take our magnetic pole which is changing north and south and we will take our sheet of copper partly covering that magnetic pole. Take the disc of copper and place it above. Now, if this pole is north this lower edge of the disc will be south. If this pole is south then this lower edge of the disc will be made north. All above the lower part will become of the other polarity—if south, north up here; if north, south up here. But when we put this copper plate or ring into place, it is inductively acted upon by the pole so as to produce currents in its plane. These currents are not extinguished when the inducing currents are, but are retained for a moment after the former cease and are ready to reverse. Consequently if the current has produced a certain polarity here in the lower edge of the iron disc that current in the plate of copper will attract the magnetism as it were, and pull it towards its own centre.

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The polarity if south or north in the disc will be drawn here towards this plate or ring which tends to retain the current which was induced in it. The under side of this ring or plate will be opposite in polarity to that which induces the current, but the upper side will be of the same polarity as the pole of inducing coil just after the impulse of current in the inducing coil is ready to reverse. When we use a copper disc and lay it down horizontally then we have two sets of parallel currents—rings slipping one over the other, and a renewal of the effect continually with every alternation.

I could amplify the disc experiments to a very great extent, Two copper discs may be taken. Now, if my explanation is right it does not really matter which of these is moved. In other words, if currents are set up in this disc which are attracted by parallel currents in the other disc, both should move continuously in a direction to bring these currents together or toward each other. I therefore put this copper disc over the pole on that side, and this other one on this side, and you will see that both of them are set in rotation. (Illustrating.) We are really shading the pole with two discs, and they are revolving in opposite directions. The copper disc may be affected by the iron disc and both revolve. (Fig. 9.) But if I modify the experiment so as to place this copper disc over the pole in this vertical position, and this iron disc in the horizontal position, there is no effect on either disc, but if I take the iron and put it in the vertical position, and the copper horizontal, both of them will revolve after I get the right conditions. My iron disc is not very well balanced. Both discs you see are revolving, but now the iron disc is at right angles to the copper. We could, of course, by properly arranging matters, set a whole mass of discs in operation in different directions, according to the conditions which were chosen. This alternating magnetic field extends away out into the air here, and we could fill it full of discs, provided we did not cut off the field, and they would all be set in motion accordingly.

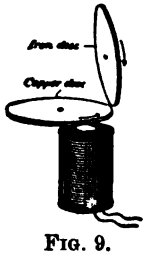

FIG. 9.

There are some other curious effects, however, produced in extending this disc experiment. Here is an ordinary steel file. If I take this copper disc and lay the steel file across the magnetic pole in this manner and then hold the copper disc near it, we see that the steel file has the property of setting the disc in

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motion. If I take two discs and place them over the steel file at the opposite ends, you will find that they will revolve as though they were geared together—one out this way, and one out the other way. And as above, an iron disc placed in this vertical position over the file will revolve, or we may place it in the horizontal position and it revolves. Here the effect is the magnetic effect—not the current effect, and with the two iron discs the rotation of both of them is produced as you see, whether they lie in that plane or in any plane in respect to the file. (Fig. 10.)

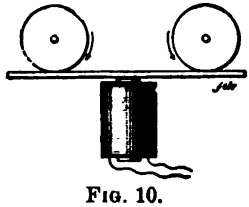

FIG. 10.

It is not even necessary to get this rotary action that we should use the file. We can take the copper disc, place it over the pole flatwise, and then simply bring another core of soft iron over the pole, but displace it a little from the axis of the other core. And you see we get vigorous rotation. In fact, this is a principle I have used in making, with some success, a small alternating motor. By simply displacing the poles and putting a copper circuit between, the rotation may be made continuous and by multiplying the number of poles a considerable exertion may be obtained.

Cast iron behaves like steel in this connection. Here we have a curious instance of a cast-iron ring on which I have simply wound a little closed coil. I place this ring over the alternating pole say in this manner, symmetrically. I get no tendency to rotation in this iron disc. I have placed the closed coil at the opposite diameter from the inducing pole. If I make the placing unsymmetrical, however, so that the coil is on one side, then you see I get rotation in the concentric iron disc but not very brisk. I simply put the iron disc in position and find that the magnetism in traveling around this ring turns the disc, while this portion of the ring which is covered with a little closed coil, prevents the magnetism from creeping aronnd the ring in such direction, that we do not get the opposing or balancing effect which would stop the disc. The closure of circuit of this coil simply prevents the propagation, as it were, of the waves of magnetism from the alternating pole in this direction at the same rate that they go in the other direction around the cast iron ring. Consequently we have a rotation of the disc in this direction, and showing us in a different way what we were getting with the file. (Fig.

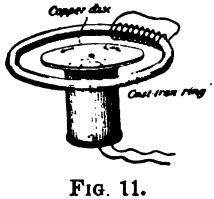

FIG. 11.

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11.) We were getting waves of magnetism which passed out along the file in each direction, and which took some time to so pass, that is, beginning in the middle of the file at the pole, and moving out and only reaching the end after a little interval; the reason being that the file, although it is not surrounded by closed circuits, as is the case with the cast-iron ring, has another property which I mentioned before—magnetic friction which opposes quick changes of the magnetism. It uses up force to effect such a change. It warms, not by induced current, but by the effort of the field to turn the molecules first one way and then the other in producing opposite polarities. The actual result of that action is as follows: We will consider the instance of the file. That we will suppose is laid across the pole. When the pole is south, the file would be north at its centre. When the pole changes to north the north in the file splits, as it were, and moves outward, while the centre becomes south, and the two norths travel out along the file oppositely, and being north poles they, of course, are surrounded by magnetic lines, and in fact are moving consequent poles for the time being.

Now we may put here a disc of copper or iron, and these magnetic poles or lines are sweeping along the file. They act like magnetic brushes that are brushing the disc around and they disappear in closing themselves up or neutralizing, as it were, at the ends. That is, when a pole in traveling goes so close to the end of the file it is so near an opposite pole as to neutralize it, at which moment the action ceases so far as those lines are concerned, and a new set are sent out to travel along, and this goes on continuously at every wave of alternating current.

We have an example here of a little alternating motor of a very small type which is built up on the principles we have been showing, only we have a different form of magnet. In this case I have a circular core. That is, I have a ring of iron which would return on itself; but I have cut a slot through it of about a quarter of an inch in width. On the sides of the slot I have placed copper circuits which are closed—closed bands in which currents can be produced. But I have offset them so that there are more on one side than on the other—so that the poles are shaded on one side and not on the

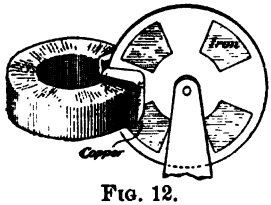

FIG. 12.

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other. If I introduce a copper disc into the slot here and put on the current, we will see that we have an alternating motor produced (see Fig. 12), and it exerts some power. This machine, however, I use for another purpose. I have two coins, and one of them I lay on my hand in this fashion just below the slot, and it is drawn in and thrown violently out, upward through the slot. (Fig. 13.) In other words, the silver coin tends to do what this disc did—continually move up through the slot. But this disc may be regarded as a lot of coins stuck together, and consequently we have continuous movement. Here we have only one disc. But we will try the other coin. With that we get no such effect. It is a counterfeit. (Laughter and applause.) But listen, (ringing the coins), there is not very much difference in the ring. One might easily be deceived. But the machine knows the difference. The silver of the genuine coin is a good conductor. Silver, even with an alloy of a baser metal, like copper, retains a large portion of its original conductivity. Consequently the currents induced in the silver are much more considerable than can be induced in this base coin, which is not so good a conductor. Anything that imitates silver does not come anywhere near it in conductivity, especially if it is expected to weigh as much as silver, in which case lead is generally one of the constituents; and this alloyed with other metals is still worse. I keep these coins in separate pockets, as you see. (Laughter.)

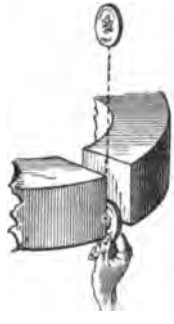

FIG. 13.

Now, there are some other curious effects of rotation which are rather modifications of what has already been shown, but they are certainly curious. They are explained on the same grounds which explain the rotations of the disc and to which I have referred. But from their uniqueness they are perhaps more interesting in some ways. They are certainly in a popular sense more interesting, because the actions are somewhat unexpected. Here is a hollow copper ball. I place a brass plate over the alternating pole, and it projects not two thirds over. I place the copper ball on the plate and you see the copper ball at once spins. Placing it on the other side it spins in the other direction. It is behaving just like a copper disc placed over another disc. Here is a little one, a smaller ball, the spinning top of the future.

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You have heard the old rhyme about the dish running away with the spoon. I am going to have it modified in this way. I have a brass dish here which will run away with a cup. We have the same spinning-top effect. It is not at all necessary that we use a plate for that purpose. I showed you sometime since the equivalency of a plate with a ring, and I shall now merely make a momentary substitution of this copper ring with a mica sheet, to rest the bodies on, and you will find that the copper ball spins in that ring as though placed on the plate. But a more surprising effect is yet to come. I shall have to put on a guard rail to the apparatus in this case to prevent the ball running away from us. I have two glass pins inserted in a plate which partly shades the pole, and I lay the copper ball against those pins. The ball rotates over this way and actually overcomes the friction of its lower side on the plate. It has to turn on a horizontal axis and its equator rubs the shielding plate. The action is very vigorous, as you see. (Fig. 14.)

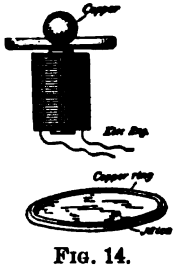

FIG. 14.

One of the interesting modifications of this experiment we will attempt to show. It is somewhat analogous to the experiment of the lamp immersed in water. I put over the core a vase of water. We have the alternating current on. But you see there is no action of the ball. It requires that we place underneath a shading disc. Now, we have a rotation of the ball in the water. This may become quite vigorous, and we obtain extra vigor by putting a copper ring in the water. This is a pretty modification of the other experiments, and has this advantage, that the ball keeps cool. In the other case the ball gets warm. The currents are so energetic that they actually warm the ball. Now the ball is rotating right in the copper dish, and sometimes when we get sufficiently vigorous action the dish and the ball both are set into vigorous rotation. Now, the dish is going about or turning. We might fill the water with small balls. I have had three of them in operation at one time rotating in different ways. (Fig. 15.)

FIG. 15.

One or two more experiments in this direction. I here have mounted a somewhat different arrangement. I have a little

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wheel or rim of copper with an iron interior. That is, it is like the armature of a dynamo wound with wire or covered with a conducting envelope. We place a wedge of iron on the pole and then I shall bring this on the one side or the other of the edge of the wedge. You probably cannot see the action, but you will perhaps take my word for it, that the little wheel is revolving very rapidly, and if I put it on the other side it revolves in the other direction as though a jet of something were shooting off that edge. This jet is nothing more than the traveling system of magnetic lines. You are all familiar with the gyroscope—the instrument which you had generally to spin by winding a cord and pulling it off the shaft. Here is a gyroscope which is the gyroscope of the future. You do not require a string or battery, except the alternating current field. You do not require any connection with the instrument. I put a centre for it to move on in the magnetic pole. Already the little disc is rapidly revolving, and I will let go of it in the ordinary way of the gyroscope, and you will see it turns about. It will get up to quite a speed in a little while and then you will see that the gyroscopic action is very beautifully manifested. Now the thing that causes rotation in this case is the little inclined frame holding the wheel. It does not lie, as in an ordinary gyroscope, horizontally, but it lies in an inclined position. The wheel is simply a copper wheel with a laminated iron core supporting the copper ring. It is getting up a very high speed now, and the gyratory rotation is consequently slow—one of the phenomena of the gyroscope. (Fig. 16 and 17.) To reverse the rotation I would do as with any

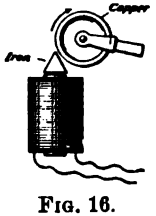


FIG. 16.

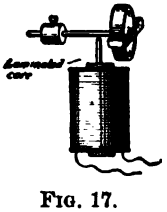

FIG. 17.

gyroscope—simply move the weight so as to bring the balance outward instead of inward, and then the rotation would be opposite in direction. Now the rotation is in the opposite way. I have over set the gyroscope by putting the weight out from the pivot so as to overbalance it.

DR. GEYER:—Have you ever taken the weight off altogether?

PROF. THOMSON:—I haven't tried that, but it is possible, I

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think, with very high speeds. But if I take the weight off the copper frame it does not retain its angular position. I need the weight to hold it in place. I must have the angle of the frame preserved. The deflective action comes into play to turn this circuit to right angles. With this experimental illustration we see that a curious series of phenomena are manifested by alternating magnetic fields.

There is but one other statement I wish to make before closing, and that is as to the marvellous capacity for the transfer of energy which an induction coil possesses. If we could imagine an induction coil, that is, a coil composed of a winding, which acts to produce currents in another winding, carried to a very low temperature, we could have the resistance of the copper to the passage of the current almost obliterated. Then we would find that we could load the copper coils with an enormous amount of current. They could probably be made of tubes and refrigerating fluids passed through them. We would find the actual amount of energy which could be conveyed from one circuit to another by a moderate sized coil and with a core of very moderate dimensions, that is, with an iron core and a magnetic circuit of very moderate dimensions, would be counted by thousands of horse-power. Our experience has taught us that even under ordinary conditions it is no unusual thing to transfer thirty or forty horse-power through a magnetic core which a man can easily lift, and do it efficiently and well. The iron part of the apparatus has very little to do with the action. We could take it out altogether if we could refrigerate our coils and wind the two coils close together. The induction coil is probably one of the most striking examples or proofs, we may say, of the fact that the actual mode of transference of energy along an electric wire is not through the copper of the wire; it is through the medium outside of the wire. The modern view of electricians, gradually becoming more and more credited, is that the wire is merely the core of a set of disturbances which are really propagated around it. That is (illustrating), if we have a wire conductor carrying a varying current, that current is merely an incident of something which is going on all around in the space surrounding the wire, in the ether—in the medium which surrounds all bodies, and which fills all space. Now, it is manifest, if this be true, if the varying current is merely an incident of this propagation of energy in that medium—put another wire

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there and you ought to have a current as an incident of the propagation, and if you coil those wires up together so as to make a coil in which two conductors lie side by side as in an induction coil, if the propagation of energy is thousands of horse-power and this current in the centre an incident of that propagation, thousands of horse-power may be represented by the currents of which this is an incident, too; or in other words, the two circuits are in the same relation exactly to that thing which represents or carries energy. The primary circuit and the secondary circuit are really immersed in the thing which is conveying electrical energy, the wire merely serving as a centre around which the energy shall be propagated. I thank you for your attention this evening, and if I haven't been very scientific, I hope I have shown some things which have been of some little interest. (Adjourned.)

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## ANNUAL MEETING.

At the annual meeting of the American Institute of Electrical Engineers, held in New York City, May 20th, the following Officers and Members of Council were elected to fill vacancies occurring under the Rules.

PRESIDENT,
W. A. ANTHONY,
Term expires 1891.

VICE-PRESIDENTS,
Terms expire 1892.
FRANCIS B. CROCKER,
FRANK J. SPRAGUE,
JOSEPH WETZLER.

MANAGERS,
Terms expire 1893.
J. C. CHAMBERLAIN,
P. B. DELANY,
HORATIO A. FOSTER,
H. WARD LEONARD.

TREASURER,
GEORGE M. PHELPS,
150 Broadway,
New York.

SECRETARY,
RALPH W. POPE,
12 West 31st Street,
New York.

The annual report of Council stated that twelve Council meetings had been held during the year, and ten meetings of the Institute for the reading and discussion of papers. One hundred and three associate members were elected who had qualified, ten have resigned, and seven have died. The total membership of all grades at the date of the report was 427. The net receipts of the year from entrance fees and dues was $4,372.14, and the net expenses $4,308.16, showing a net surplus of $63.98. The balance in the hands of the Treasurer was $249.26 to the credit of the General Fund, and $350.00 to the Building Fund. By an arrangement with the American Society of Mechanical Engineers, the future headquarters of the Institute will be at the House of that Society, No 12 West 31st Street, New York, where meetings

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will be held hereafter, and to which all communications should be addressed.

At the meeting of Council held June 17th, Dr. Schuyler S. Wheeler was elected Vice-President to fill the vacancy caused by the death of Major O. E. Michaelis; and Francis R. Upton, Manager, in the place of Henry Van Hoevenbergh, resigned.

JUNE 25th, 1890.

# American Institute of Electrical Engineers.

## ELECTED TO ASSOCIATE MEMBERSHIP.

At the Council Meeting, May 20th, 1890.

| Name. | Address. | Endorsed by |
|---|---|---|
| BUNCE, THEODORE D., JR. | Battery Expert, The Julien Electric Traction Co., 239 East 27th St., New York City. | Wm. Bracken. J. C. Chamberlain. R. W. Pope. |
| BROOKS, MORGAN. | Secretary and Treasurer, St. Paul Gas Light Co., St. Paul, Minn. | W. B. Vansize. G. W. Blodgett. E. T. Gilliland. |
| PECK, EDWARD F. | General Sup't, Citizens Electric Illuminating Co., Cor. Navy St. and DeKalb Ave., Brooklyn, N. Y. | G. M. Phelps. T. C. Martin. Jos. Wetzler. |
| JONES, F. R. | Sup't of Construction, The Western Engineering Co., Kearney, Neb. | Edward L. Nichols. D. C. Jackson. H. J. Ryan. |
| BRADLEY, FRED. W. | United Edison Mfg. Co., 27 Front Street, Schenectady, N. Y. | W. S. Andrews. W. G. Whitmore. J. C. Bennett. |
| BELL, Dr. LOUIS. | Editor *Electrical World*, 167 Times Building, New York. | W. J. Johnston. W. A. Rosenbaum. Clarence E. Stump. |
| WILLIAMS, ARTHUR S. | Electrician, American Telephone and Telegraph Co., 18 Cortlandt St., New York City. | F. A. Pickernell. Holbrook Cushman. G. A. Hamilton. |
| STOREY, IMLE E. | Electrician and Manager, Storey Electric Drill and Power Co, 16 Broad St., New York City. | W. A. Rosenbaum. H. W. Blake. R. W. Pope. |
| WATTS, H. FRANKLIN. | Electrical Engineer, 1209 11th Street, Altoona, Pa. | W. A. Rosenbaum. C. E. Stump. R. W. Pope. |
| LOZIER, ROBERT T. E. | Electrical Expert, The Edison United Mfg. Co., 65 Fifth Ave., New York. | W. S. Andrews. Gilbert Wilkes. Chas. Wirt. |
| SWEET, HENRY N. | Chief of Patent Bureau, Thomson Electric Welding Co., 89 State St., Boston, Mass. | Elihu Thomson. A. L. Rohrer. John C. Lee. |
| MARKS, LOUIS B. | Graduate Student, Cornell University, Ithaca, N. Y. | Edwd. L. Nichols. H. J. Ryan. R. W. Pope. |

Total 12.

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## ELECTED TO ASSOCIATE MEMBERSHIP.

At the Council Meeting, June 17th, 1890.

| Name. | Address. | Endorsed by |
|---|---|---|
| DUNDERDALE, CLEAVELAND F. | Agent Westinghouse Electric Co., 146 Adams St., Chicago, Ill. | C. O. Mailloux.<br>H. Ward Leonard.<br>Chas. W. Raymond. |
| HOLCOMB, EUGENE R. | Electrician, Agency Thomson-Houston Electric Co., 234 Montgomery St, San Francisco, Cal. | A. L. Rohrer.<br>G. F. Curtiss.<br>H. Lemp. |
| SINCLAIR, H. A. | Electrical Engineer. The Tucker Electric Co., 950 Bedford Ave. Brooklyn, N. Y. | C. O. Mailloux.<br>Jos. Wetzler.<br>T. C. Martin. |
| CHAMBERLAIN, F. H. | Electrician. Metropolitan R. R. Co. 2411 P. St., N. W. Washington, D. C. | C. O. Mailloux.<br>Jos. Wetzler.<br>T. C. Martin. |
| CUTTER, GEORGE | Dealer in Electrical Supplies, 192 Fifth Avenue, Chicago, Ill. | E. Wilbur Rice, Jr.<br>Elihu Thomson.<br>Merle J. Wightman. |
| COBB, JOHN S. | with S. R. Krom, General Manager and Mining Engineer, 151 Cedar St., New York. | Jos. Wetzler.<br>Geo. M. Phelps.<br>T. C. Martin. |
| FISKE, J. P. B. | Electrical Engineer, Thomson Houston Electric Co. Lynn, Mass. | G. F. Curtiss.<br>A. L. Rohrer.<br>W. H. Blood, Jr. |
| REIST, H. G. | Electrical Engineer. Thomson-Houston Electric Co. 113 Franklin St, Lynn, Mass. | A. L. Rohrer.<br>W. H. Blood, Jr.<br>G. F. Curtiss. |
| CAHOON, JAS. B. | Electrical Engineer. Thomson-Houston Electric Co. 257 Washington St. Lynn, Mass. | E. W. Rice, Jr.<br>A. L. Rohrer.<br>G. F. Curtiss. |
| EKSTROM, AXEL. | Electrician. Thomson-Houston Electric Co. Lynn, Mass. | G. F. Curtiss.<br>E. W. Rice, Jr.<br>A. L. Rohrer. |
| OWENS, R. B. | Superintendent, Greenwich Gas and Electric Light Co. Greenwich, Conn. | T. C. Martin.<br>Louis Duncan.<br>E. F. Peck. |
| COLGATE, GEO. L. | Electrical Engineer. Bedford Electric Co. Bedford City, Va. | Cecil P. Poole.<br>T. C. Martin.<br>Jos. Wetzler. |
| MYERS, GEO. FRANCIS | Laboratory of Wm. Stanley, Jr. U. S. Electric Light Co. Newark N. J. | William Stanley, Jr.<br>S. S. Wheeler.<br>Ralph W. Pope. |
| MASON, AUGUSTÉ F. | General Manager, Simplex Electric Co., 620 Alantic Avenue Boston, Mass. | Jos. Wetzler.<br>T. C. Martin.<br>C. J. Field. |
| LUFKIN, HARVEY L. | General Agent, "C & C" Electric Motor Co., 404 Greenwich St. New York. | R. N. Bayles.<br>Jos. Wetzler.<br>T. C. Martin. |
| POWELL, WILLIAM H. | New Britain, Conn. | Wm. A. Anthony.<br>Edwd L. Nichols.<br>Harris J. Ryan. |
| FRANCISCO, M. J. | President and General Manager, Rutland Electric Light Co., Rutland, Vt. | Jos. Wetzler.<br>T. C. Martin.<br>C. J. Field. |

Total 17,

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## TRANSFERRED FROM ASSOCIATE TO FULL MEMBERSHIP BY COUNCIL, JUNE 17th, 1890

(Approved by Board of Examiners, June 10th, 1890.)

| | | Elected Associate Member. |
|---|---|---|
| LAWSON, A. J., | Electrical Engineer and Contractor, Montreal, P. Q. | Mar. 18, 1890. |
| DAVIS, CHARLES H., | Consulting Electrical Engineer, 120 Broadway, New York. | May 18, 1890. |
| BROOKS, MORGAN, | Sec'y and Treas. St. Paul Gas Light Co., St. Paul, Minn. | May 20, 1890. |
| JACKSON, DUGALD C., | Asst. Engineer, Railway Dept., Sprague Electric Railway and Motor Co , New York. | May 3, 1887. |
| JACKSON, FRANCIS E., | Edison Lamp Co., Harrison, N. J. | Jan. 3, 1888. |
| BELL, DR. LOUIS, | Editor *Electrical World*, New York. | May 20, 1890. |
| STEBBINS, THEODORE, | Thomson-Houston Electric Co., (Railway Dept.) Boston, Mass. | July 9, 1889. |

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*A paper read before the Annual Meeting of the American Institute of Electrical Engineers, New York, May 20, 1890.*

# ELECTRICITY IN THE NAVY.

BY GILBERT WILKES.

I have taken as my title "Electricity in the Navy" and shall give in my paper the general conclusions derived from five years' more or less intimate connection with the application of electricity in our naval service.

The electrical engineer has little to do with the placing of the dynamo room, which is of necessity governed by the arrangement of the ship as a fighting machine. I shall, therefore, merely consider the power and apparatus of the plant, commencing with the engines.

Both in this country and abroad, compound condensing engines have been used, some having separate condensers, some exhausting into the main condensers of the ship, but the preference seems to be in favor of simple double acting, high-speed engines, the reason being that the power used for electrical purposes is so small in proportion to that of the main engines of the ship (only about an average of one per cent.) that the saving does not pay for the additional complication and cost. However, with a given plant, the engine should be constructed to allow little variation of speed under large changes of steam pressure, in order to take advantage of the main condenser when possible.

In our service both horizontal and vertical engines are now in use, the preference in some cases being the result of the shape of the available space. No data has yet been obtained as to the most economical type, but both are doing good service, the mishaps having been due to accidents. Of late years all of the engines put in for electric lighting have been high-speed, the largest of about twenty-five horse-power and running at 400 revolutions.

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The important points in the consideration of a marine dynamo are:—

First:—It should be direct driven. The reasons are obvious, as, not only is the space taken up by the belting valuable, but in a sea way the danger of running belts must be considered, especially when it is taken into account that naval vessels are fighting machines and the possibility of accidents must be reduced to a minimum.

Second:—It should be compact. This is a natural extension of the above. Even now it is difficult to find room for all of the machinery, stores and ammunition, besides providing room for berthing the crew on a modern man-of-war.

Third:—It should be free from liability to injury by salt water, and not too subject to mechanical damage.

In this respect there remains room for considerable improvement, the latest dynamos now better filling this requirement than did the old "L" machine on the Trenton in 1883, the first dynamo afloat in our navy and which ended its useful career in the great storm at Samoa last year, when it ran until the water had put out the fires under the boilers.

On board ship, salt water and damp air get everywhere and within the last year a number of cases of slight burn out have occurred in armatures, which, when installed, measured high in the hundreds of thousands of ohms insulation. The dynamo should not be easily harmed. The dynamo room is now always low down in the ship, under the protective deck (if there is one), and when the light is not in use, the room is very dark, rendering careful inspection difficult.

Fourth:—The dynamo should have small effect upon the compasses. This point has received little attention though it is a matter of great importance, as the effect on many vessels is so large that, in order to work up the day's run, it is necessary to know the hours during which the dynamos have been in operation. Complete deviation tables are therefore necessary for the two cases. In different types of dynamos the effect with a twenty horse-power machine, at a distance of 12 feet, will vary from less than one-twentieth of the horizontal component of the earth's magnetism, to several times the strength of the horizontal component. The latter is, unfortunately, rather the rule than the exception, and, in consequence, the position of the dynamo

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room has to be well borne in mind in locating the standard compass.

FIFTH :—It should be easy in running and require but little attention. The machine should be non-sparking, under constant load and also be able to stand sudden large changes of load with little sparking. This is necessitated by the fact that the dynamos now supplied for incandescent lighting are also used for search light work and the conditions are aggravated by most of the search lights having hand regulation only. Thus, with a 200 ampere machine, not only are from 50 to 100 amperes thrown suddenly on and off, but at the moment that the operator at the projector brings the carbons together, the dynamo is suddenly called upon to deliver over three-fourths of its total capacity.

SIXTH :—It should be efficient and run cool, the former in order to avoid the waste of energy and a corresponding amount of the coal supply and also in order to avoid over-heating. The dynamo rooms on shipboard are, at best, warm, notwithstanding the motor fans, which are now usually supplied and thus the safe limit of extra heating is reduced. At the same time consideration for the attendants requires that the cramped space be kept as cool as possible.

SEVENTH :—The dynamo should maintain a constant potential at all loads. This is of course accomplished by compounding, and, as there is only about three per cent. drop, it is usual to compound exactly, or to only over-compound enough to allow for the decrease in the engine's speed with load.

EIGHTH :—The dynamo should be light. The reasons are obvious, but it is considered last, because usually a careful study of the materials, and arrangement of the plant, can accomplish more towards reducing the total weight than the strict adherence to a specification of watts per pound of dynamo. Thus, consider the difference between the weights of a 40 horse-power ship plant on a five watts per pound specification, and upon a four watts specification. Two 200-ampere, 80-volt dynamos, with their share of the bed-plates, will only weigh about 7,500 pounds. Twenty per cent. of this will be about 1,500 pounds, an amount, a large portion of which can really be saved in some cases by more careful attention to the amount of wire and moulding employed.

Naturally no one dynamo can best fill all of these conditions, and while the order in which they are above arranged will usually

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approximate to their relative importance, special cases arise which demand a re-arrangement. Thus, on torpedo boats, the most important quality is small size. With this in view, numerous devices have been placed upon the market and faithfully tried, but none have to my knowledge proved satisfactory. The requirements of high efficiency, low speed and low heating, all give way in this class of dynamo to the necessity of compactness and light weight. Good results were hoped for from the Parsons turbo-electric generator, but experience at Newport demonstrated that the turbine was so inefficient in its consumption of steam as to place its use out of the question. There is as yet no apparatus to satisfactorily fill this want.

Up to the present all of our ship plants contain one set, or two or more similar sets, each composed of an engine and one direct driven dynamo. The largest of these are of 200 amperes capacity; a very convenient unit, but one which can be doubled in capacity with advantage in ships which are not light below decks and which are likely to soon have extensive motor applications: for example, vessels of the monitor type.

The voltage in use in the navy is eighty volts, this having been fixed upon as a mean between the most efficient pressure for the incandescent system and the voltage necessary for the search lights, to which current is supplied by the regular service machines. The incandescent lamps have given excellent results as to life from the very start, owing in great measure to the fact that low efficiency lamps are always used, nothing more economical than four watts per candle power being usually required.

Search lights of fifty volts and from fifty amperes up are used, two or more being supplied, according to the size of the ship Some of these are imported, others are made in this country.

The two wire system has always been used in the naval service, the ship never being allowed to form the return circuit. On account of the present beginning of motor work on board ship and the future developments confidently looked for, the direct current has always been used. Motors have thus far been used only in driving small fans up to one half horse power, for hoists, and in one case, a motor has been used for training one of the large guns—on the "Chicago." There are numerous small engines about a man-of war varying from one to fifty horse power. Some of the smaller ones might even now be replaced with advantage by electric motors, but it must be proved in each case, that the

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motor not only does the duty as well as the engine it replaces, but also that it and any increase necessary in the generating plant, take up less room and weigh less than the engine and its piping. This, of course, will always be the case where very small engines are replaced, and, as the tendency is to increase the capacity of the dynamo plant, it may not be long before motors may look for a larger field on board ship.

All circuits are water-tight from dynamo to point of distribution, the cut-outs having stuffing boxes through which the lead covered wires enter. Even the switches and attachment plugs for portables are required, in certain places, to be watertight.

One electrical application that presents many advantages on board a man of-war, especially when on a foreign station, is electrical welding. However, when it is introduced on shipboard, the pressure of the generator should be reduced to eighty volts, in order that in case of emergency it might be used for lighting purposes, while the welders should have several sets of adjustable clamps. Welding machines have not yet been actually used on shipboard, but it is to be hoped that their introduction is a development of the near future. They can not supplant any of the existing dynamos, owing to the necessity of motors, but must come in to occupy a place of their own, to almost entirely supplant the ship's forge and add to the general useful equipment.

Thus the man-of-war is the proper field for nearly every form of application of electricity and when the storage battery becomes more suited to the service there required, there is no doubt that it too will come in for its proper share of usefulness.

As to the naval work on shore in the electrical field, little need be said, as the practice at naval stations must be similar to that in ordinary commercial work. However, a navy yard is an ideal place for the erection of a central station for light and power. The streets must be lighted; closely grouped about the station are offices and large shops needing light in the dark afternoons and power for motor work; then in an outer approximate semi-circle are the officers' quarters, finally there are anchor chains to be welded, boiler tubes to be repaired, and numerous other similar operations which can be better accomplished by the welder than by any other known means. This in an ideal plant will call for arc lights, incandescent lights, constant potential motors, a welding generator and welders. The

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complete combination will probably not be realized at any one place within several years but a good beginning has been made in the arc light plant recently installed for outside and shop lighting at the Washington Navy Yard, and the progressive plan adopted by the department leads us to hope that the shore stations will rapidly receive the benefits already enjoyed on shipboard. Owing to the usually close grouping of the buildings and to the demands for motors, it is probable that in only exceptional cases will the alternating current be used extensively. Good use is already being made of small motors for drilling purposes at the New York Navy Yard, where several are in constant operation, having driven out the portable steam engine, countershafting and belting.

The applications of electricity in the navy have always been on the increase, and any one who has served one cruise with oil lamps and one with electric lights and motors, will understand the favor in which the increasing use of electricity is held by naval men.

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DISCUSSION.

DR. OTTO A. MOSES:—There is a very interesting point touched, about which I would like to inquire; whether Mr. Wilkes has himself made observations as to the deviation of the compass on board ship

MR. WILKES:—I would say that I have not made any observations on shipboard; but the observations have been made by navigators and turned into the office of the Naval Inspector. I have seen the reports and I have made the tests on shore myself. The effect does vary between $\frac{1}{10}$ of the horizontal component of the earth and as high as 5, 6 and 7 times this component at a distance of 12 feet.

DR. MOSES:—This subject came up before a meeting of the National Electric Light Association when a Lieutenant of the Navy declared, to my astonishment, and I think to that of the other members of the Association, that there was no action on the compass at all. Have you tried experiments with the alternating current to see if that would affect the compass?

MR. WILKES:—I have never tried the alternating current because none of our ships have alternating current dynamos on board. As to the exact amount of deviation on board ship caused by the dynamo, I will state one instance in the case of the Chicago where the variation is two per cent. and it was the variation on the Yorktown, the amount of which I have forgotten, which was the cause of my investigations of dynamos before they are placed on board ship.

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MR. TOWNSEND WOLCOTT:—I would like to ask Mr. Wilkes if he has ever experimented with the class of dynamos like the Continental and the Eickemeyer, called "iron-clad dynamos"—and whether there is really much difference in their effect.

MR. WILKES:—I would answer that I have. Those are the small deviations that I referred to.

MR. R. N. BAYLES:—In setting an engine aboard ship is particular care taken to set it so that the plane of the fly wheel is either fore and aft or thwart-ships? This point came out in connection with a proposed system of lighting our light-ships with an incandescent plant. Those ships roll and pitch a good deal, and one objection raised to this plan was that in case of high running machinery on board a ship, pitching around as they do, we would have the tendency of the wheels to maintain their plane of rotation—the gyroscopic effect, and that the effect would be to maintain the strain on the bearings and cause them to heat.

MR. WILKES:—I would answer that the main trouble with heating on board our men of-war has been from having the axes of dynamo and engine faced to thwart-ships, in which case the oil is likely to fly from the bearings and it is so bad that where the available space will allow we get the shaft fore and-aft. But our space is usually so cramped that we are apt to make the most of it.

MR. BAYLES:—The remark was made that this effect of the dynamo on the compass could of course be corrected. I would like to ask if there is any particular method of correcting this effect on the compass, assuming that the load is variable when it is running.

MR. WILKES:—I would answer that the effect on the compasses is not due to the lamp load as far as observation goes. The dynamos being compounded of course always exert the same effect. The mains are run so closely together that their effect is nil. I believe that in the English service where they use the ship as a return, they have considerable trouble from this cause.

MR. BAYLES:—But can it be corrected and is there a practical method of correcting it?

MR. WILKES:—I believe it has been suggested to use a larger electro-magnet to correct it. But it has never been tried in this country, and I believe that the easiest plan of correcting it is to get a dynamo which doesn't have a large external field.

MR. E. T. BIRDSALL:—I would like to ask if that 12 feet Mr. Wilkes speaks of, was clear space or were there any iron bulk heads intervening?

MR. WILKES:—The measurements were either made in engine rooms or machine shops In the cases where the deviation is least the iron was not uniformly placed at all. It was just as you find it in any machine shop where you go to see a dynamo built, for testing it.

MR. BIRDSALL:—On almost all that I have seen of the cruisers

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there was at least an iron partition, I think, between the dynamo room and any of the compasses. We know that iron of that sort has some shielding action.

Mr. Wilkes:—The deviations have been found on shipboard and I have often thought of the shielding action of those bulkheads, but I believe it is anything but shielding, because they are not complete magnetic circuits and they only bring the lines of force close to the position which the compass occupies.

Mr. Robert S. Dobbie:—I would like to ask the lecturer if he attributes the effect only to the leakage of magnetism from the fields of the dynamo, or does he think it is the effect from the main going to the lamps. I have had a little experience with that in an alternating machine—one of the early types of Siemens machines on board a merchant vessel, and the waste of magnetism is much greater than in modern machines, and a compass adjuster from Southampton, I forget his name, a well-known man, came on board and made the most elaborate tests. The ship was wired returning through the hull. That is, the current was grounded after passing through the lamp and no perceptible difference was found on that ship, not the slightest.

Mr. Wilkes:—The experiment has been roughly tried by changing the position of the compass in reference to the mains and keeping approximately the same distance from the dynamo. It leads to the conclusion that the effect does come, to all observable amounts, from the dynamo itself. Did I understand you to say that you had had other experience?

Mr Dobbie:—Well, the machine was of the alternating description, so I suppose the lights made very little difference, but the magnetism escaping from the field magnets of the dynamo was, I should say, very much greater than with the modern machines. The theory of the dynamo was not so well understood in those days. There were two dynamos, an alternating dynamo with a field of eight magnets, and a small exciter.

After the election of officers the meeting adjourned, to reassemble at Boston, May 21st.

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# AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

At the meeting of the Council, June 17th, 1890, the following preamble and resolutions were unanimously adopted.

*Whereas*, Mr. T. C. Martin having been a member of this Board for the past six years continuously, in the various capacities of Secretary, Manager, President and Vice-President, and

*Whereas*, during the whole of that period he has devoted himself to the affairs of the Institute with unremitting zeal and fidelity,

*Resolved*, that the council, upon his retirement from office, and in recognition of his valuable services, hereby tender to him their heartiest thanks and good wishes, coupled with the assurance of their warmest esteem ; and

*Resolved*, that this resolution be printed in the transactions of the Institute, and that the Secretary forward a copy to Mr. Martin.

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# GENERAL MEETING AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

MAY 21ST, 1890.

MR. R W. POPE called the meeting to order and said:

Gentlemen, we are assembled here under the auspices of the Massachusetts Institute of Technology, of which General Walker is the distinguished President, and I have the honor of announcing that he will now give you a brief address of welcome.

GENERAL WALKER:—Mr. President and Gentlemen of the American Institute of Electrical Engineers: It gives me very much pleasure, on behalf of the corporation and faculty of the Institute of Technology, to welcome you to these halls. We feel it to be a great privilege to receive on this occasion a body of men so justly and widely distinguished for their acquirements and for their positive contributions to knowledge. We trust that you will make yourself entirely at home in these buildings, which are dedicated to industrial science, and to the promotion of the useful arts, and whatever we, on our part shall be able to do toward the pleasure and practical success of your meeting, will be done most thoroughly and most gladly. We have on previous occasions been permitted to receive here the American Society of Mechanical Engineers and the American Society of Mining Engineers, and in each instance we felt this to be a high privilege. Not only our Faculty but our students have derived great inspiration from these gatherings. I know of nothing that can give a stronger impulse to generous young men pursuing laborious courses of study, than to see those who have already distinguished themselves in the professions to which they aspire going familiarly in and out among them and hearing them participate in debate on subjects of practical present interest to the profession. For our students' sake, therefore, as well as for our own pleasure and instruction, we welcome you most heartily to

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the Institute of Technology. Especially are we gratified that the present occasion gathers here the recognized leaders in that department of thought and research on which is concentrated so much of the scientific and practical interest of to-day. You, gentlemen, are dealing with that mighty and mysterious force to which the whole world is looking for the solution of many of the most serious difficulties and perplexities of life, for a generous enlargement of the sphere of human power and for triumphs greater far than man has yet achieved in his unceasing struggle with the material conditions of existence. Already nearly one hundred of our most earnest students are striving with unstinted labor and pains to qualify themselves to become your juniors and colleagues, and in time your successors in the exalted profession which you so fitly represent.

Right happy am I, Mr. President, that I may address these we coming remarks to one on whom the laurels of peaceful triumphs have been heaped almost beyond the privilege of the greatest inventive minds of history. (Applause). Of these you may rightfully be more proud than ever conqueror was of the spoils of war and the trophies of bloody victory. In the name and on behalf of the Institute which I represent, I congratulate you, sir, on the splendor of your achievements and on the purity of your well-earned fame. And again, with all my heart, I bid you and your honored Association welcome to the Institute of Technology. (Applause).

PROF. THOMSON:—Gentlemen of the Institute: It is surely beyond my power to respond to the sincere welcome which we have received at the hands of the Massachusetts Institute as gracefully as General Walker has extended it. The Institute, of course, is well known to you. It is an Institution which has turned out very many of the leading engineers of the country, and to-day it is contributing its share to our profession, and in fact I may say a very large share. I have reason to know that the training which is given here at the Institute is of the greatest value in fitting young men to take up the practical work of engineering. It is, therefore, fitting that the Institute of Electrical Engineers should make its headquarters here. I need not enlarge on the facilities possessed by the Institute of Technology for demonstrations. We shall probably see later that if our papers need illustrating, we can be supplied here with experimental arrangements. And I may add further that I have a sort

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of sympathy with General Walker in the welcome which he has so cordially given from the fact that our headquarters are in this vicinity and I may say that I also welcome the members of the Institute just as sincerely to Boston and its surroundings. We hope to be able to make the stay of the Institute as pleasant as may be during the course of this meeting. I have nothing further to say, except that we are very thankful, and I have no doubt that every member will say that he is very thankful for the opportunities here offered and for the hearty welcome that General Walker has given us.

In opening the meeting I will state that the Secretary has some announcements which he desires to make.

THE SECRETARY:—Mr. President, it may interest those of the members who were not present at the business meeting held in New York last evening, to be informed that the following gentlemen were elected to fill the vacancies caused by the expiration of the terms of the officers as named in the programme.

For President, Professor W. A. Anthony, of Manchester, Connecticut; for Vice-Presidents, Francis B. Crocker, Joseph Wetzler, Frank J. Sprague; for Managers, H. Ward Leonard, P. B. Delany, H. A. Foster, J. C. Chamberlain; for Treasurer, George M. Phelps; for Secretary, R. W. Pope.

To-morrow's work will be play. It is to be devoted, if we pass through our programme successfully to-day, as we hope to do, to a trip which the West End Railway Company will arrange over its line, and a visit to the new Power Station in the forenoon, and in the afternoon a trip will be taken to the Thomson-Houston factories, which will be opened to the inspection of our members, and under suitable escort, so that everything we trust will pass very agreeably, as such affairs usually do in this city.

The dinner at the Boston Electric Club this evening will take place at 6.30 and it is desirable that the members assemble at the Parker House promptly. The reception rooms will be opened before that time, and the members of the Institute who have announced to the Secretary that they will be present at the dinner will find their places assigned to them, and their names at the plate.

The diagram of the table will be ready for examination in the reception room. There will be about 200 present.

The programme of papers will be changed slightly. The paper of Mr. Marks will be taken up this forenoon, and the one on a

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New Photometer, by Doctor Nichols, will be read at the afternoon session. This change is made to accommodate Mr. Marks, who has an important engagement elsewhere.

I notice among the audience our newly elected President, and I trust he will come forward now, as is the custom, and take the chair.

On account of President Anthony's recent indisposition he does not feel quite able to assume the duties of the chair this morning.

The first paper on the docket is Electric Lighting in the Tropics, by Wilfrid H. Fleming of New York City. In the absence of Mr. Fleming, Mr. Wetzler will present this paper.

Mr. Wetzler read the paper.

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*A paper read before the General Meeting of the American Institute of Electrical Engineers, Boston, Mass., May 21st, 1890.*

# ELECTRIC LIGHTING IN THE TROPICS.

BY WILFRID H. FLEMING.

One of the chief difficulties that an engineer experiences who is called upon to install a plant of any considerable size in tropical countries is the trouble of procuring any kind of skilled labor for this particular class of work. Another difficulty is that he is so far from his base of operations—the factory—which will often lead him to depend upon himself in overcoming obstacles that arise from time to time as the work progresses. Language and the heat, as well as fevers, are minor affairs.

Electric lighting has already gained many warm adherents both in the East and West Indies, more especially in the former where plants of considerable capacity have been in active operation for the past eight years. It is especially adapted for use in houses in warm climates, such as that of India, where the old-fashioned "punkah" is in daily and nightly use for cooling the rooms, accompanied with its attendant noise as the "punkah wallah," a servant pulls it backward and forward causing the continual flickering of the lamps or gas. That system will, in time, I hope, give place to the noiseless motor fans and steady incandescents, thus enabling the Anglo-Indian to read and rest in comfort.

A central station plant that the writer was engaged upon lately in one of the chief cities of the West Indies, would compare favorably in size and equipment with one situated in a city of a corresponding number of inhabitants in the United States. Alternating current dynamos of a capacity of 4.500 16 c. p. lamps were employed for lighting the chief stores, theatres and private houses, and 600 arc lights of 1200 c. p. each lighted up the main streets and parks.

It was at first intended to run a small plant in connection with

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the existing gas works, more as an experiment than with a view to actual financial success, but in the space of six months the station was more than trebled from its original capacity.

The people took to it from the start, paying cheerfully the prices that were demanded. To an indolent race it was a great boon. Money to them, it would appear, was of less account than the trouble and work called upon to go around and light up the different oil and gas lamps, since all the lights were switched on the different circuits at sunset. In the tropics, as is well known, there is no twilight. Darkness comes on within 10 minutes of sundown and the whole plant practically goes into operation at once.

The construction work on this particular plant was necessarily somewhat slow, as men unaccustomed to erect a 30 or 45-foot pole took their time to do so, in which operation they received the appreciation of the usual army of idlers. Poles suitable for carrying a number of circuits had to be imported from the United States, as well as the ornamental wooden columns for supporting the lamps in the parks and public squares. Poles of native growth could not be found straight enough and even if of sufficient length were weak. Some poles could have been had from a tree called the iron wood tree. This wood, however, is of so close a grain and so very heavy that it was out of the question to use it. Many of the business streets were not more than from 20 to 30 feet across including the sidewalks. Moreover, as curtains or awnings are stretched overhead from side to side by the owners of the stores to shelter and protect their goods from the sun's rays, it was impossible to erect a pole line down these streets, I found it better to run a two-inch iron piping up the side of the houses every 150 feet to a point 6 feet above the coping stone, and then attaching to the top of this pipe a T, inserting in this T wooden cross arms to which the insulators were attached in the usual manner. It must be borne in mind that the houses are not of very great height. Where this arrangement was impracticable owing to the varying heights of the houses, I inserted strong iron brackets in the buildings set in with cement and well painted with rust-proof paint.

In India considerable care has to be exercised in putting up a pole line. If you want your work to stand any length of time, the base of the poles for one-sixth of their length must be thoroughly well creosoted to resist as far as possible the ravages of an

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insect called the white ant or "termite." These insects live on wood. They attack even the wood-work of the houses and soon reduce the thickest timber to a mere shell. They live in trees and construct nests of great size like small sugar casks made of particles of gnawed wood and cemented by a kind of gluten. They are so strongly attached to the branches that they cannot be shaken down even by violent storms. It is a good plan to paint the poles 8 feet above the surface of the ground with good gas tar if obtainable. In these climates special attention should be given to protecting the working parts of arc lamps, owing to the fact that rain occurs only for about three months of the year and to make up for this loss, the humidity of the atmosphere is remarkable. It is not at all infrequent to find early in the morning the bottom carbon holders full of water unless provision is made for draining this off. During the hot season, a breeze springs up between 9 and 10 o'clock in the morning and the ground being dry, the dust is terrific. Insects of a large size —much more so than those found in the northern climates— bats and small birds attracted by the glare are found either in the globes or lying at the base of the lamp posts in large quantities every morning; and the wholesale slaughter that takes place nightly seems to have no effect in diminishing these pests.

It was found better, therefore, on the arc service to give a man about 25 lamps to trim and clean per day, and the native entrusted with this work was held responsible and if the lamps were found in a dirty condition he was fined, which usually had a good effect.

In the construction of station buildings one is guided much by the facilities for procuring stone brick or other suitable material in that particular locality. Galvanized iron is sometimes used for roofing, but more frequently roofs are constructed of a sun-baked clay tile, provision being made as is usual for an ordinary wire tower for distributing the various circuits. A point to be noted is that the engineer should construct his rain gutters for taking off the storm water at least double the size that is ordinarily allowed for temperate climates. Roofs and the outsides of the buildings are white-washed.

To give an idea of the heat from the sun, I may mention that I had to replace considerable quantities of insulated wire after it had been up only a short time, the insulation in places sagging right away from the copper wire and finally dropping off.

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During the rainy season prevailing in the West Indies in the months of June, July and August; and in the East Indies, known by the name of the south west monsoon, and prevailing from May to the latter part of August, electrical storms occur almost daily. They are often exceptional in violence, and much trouble and anxiety arises from possible damage to line, lamps, and dynamos, even though protected by good lightning arresters.

While a heavy storm was in progress one night last summer in the West Indies, I noticed when in the station a curious effect of a flash that fused the lead strips on an ordinary saw-tooth arrester connected with one of the incandescent circuits. The strips were entirely destroyed or volatilized and what was before a polished plate of brass was now tarnished with a film of the lead vapor, and there was distinctly marked as if photographed on the plate a zig-zag streak, in all appearance like a photograph that had been taken of lightning. Engineers, during the prevailing season of storms, should take particular pains that their lines and machines are thoroughly well protected and that the arresters have good earth connections.

A sad case came under my notice that happened at a temporary installation for illuminating a camp in Poonah, in the Bombay Presidency, with arc lamps in honor of a visit of an influential Rajah. Whilst the festivities were taking place in the evening, a heavy storm occurred. Lightning entered on the line, no provision had been made for diverting its course, and it destroyed the dynamo besides killing the native oiler who just at that moment was engaged in filling up the oil cups on the bearings. He was either thrown or fell across the commutator end of the dynamo, as he was found in that position, his hands much burnt as well as his feet.

In the year 1877 the first commercial arc lamp was in use at the offices of the Bombay *Times*, and if I remember correctly it was the first light shown in the Indian Empire. From that date on, the demand for lighting has been on the increase; but pretty nearly all the work has been confined to isolated work and small central stations, cotton mills, sugar and indigo plantations, government buildings and large private dwelling houses. Places of business and offices do not require lighting, as business is conducted by the merchants only from 7 o'clock in the morning till 4 in the afternoon. The inhabitants of hot climates necessarily spend much of their time out of doors and are fond of social

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gaiety. They have been famous for centuries for skill in illuminating, and this fact has added much to the popularity of arc and incandescent lamps, which as is well-known, particularly lend themselves to artistic illuminating purposes. From this knowledge, in the early part of the year 1885, I imagined that it would be a financial success to get together a travelling portable electric light plant, consisting of a vertical boiler, engine and two dynamos, one an 8 arc light machine and the other a 100 light incandescent, both mounted on a stout frame which rested on a pair of bisel trucks. This work was carried out, and I was kept actively employed for many months in going round to different large Indian estates and native palaces for the fetes that attend the various religious and family ceremonies that the wealthy natives are fond of indulging in. Large sums of money are spent and the festivities often last for a week or longer. It turned out to be as I surmised it would, a regular "bonanza," until on one occasion in bringing the unwieldly contrivance down a steep hill on one side of which was a ravine, it fell over; and it is needless to relate, that the whole apparatus was seriously damaged. I found it would not pay to patch it up again, so after stripping everything that was portable I left the remainder to lie and rust in the tropical vegetation.

Owing to the high price of coal, which is a costly article in the tropics, ranging from $8 to $50 per ton delivered, it is well to employ the most efficient and economical engine for motive power, more especially for central station work. In the station previously referred to, we were running with high speed compound condensing engines with satisfactory results.

In many sugar plantations in the West Indies where the installations are of a comparatively small size, economy in this direction is not practised as the amount of steam used is not missed, the boiler capacity on estates ranging from 100 H. P, to one at Cienfuegos, Cuba, of 2,500 H. P. It behooves the engineer, however, who has charge of a plant to exercise considerable care and watchfulness over his native firemen. The natives, as a rule, I have found, if treated with kindness and forbearance, show an aptitude in learning and taking hold that is often remarkable, more so than with some of their brethren of a lighter color who because they have been taught how to start and stop a dynamo or trim an arc lamp, give themselves all the airs of an expert in

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electrical matters, and have got beyond that stage when they are willing to be instructed or to be obedient to orders, an unwillingness that sometimes leads to disastrous results.

The types of machines chiefly in use in the East Indies are those of English and French manufacturers, Siemens, Gramme, Silvertown and other well-known types. Those in use in the West Indies and South and Central America are generally of American make, and the market is not a small one. The great strides that both the foreign and home companies have made in the last two or three years in the supply and equipment of electrical plants for these distant lands are very evident signs that this particular business is receiving great attention at the hands of local merchants, planters and city or town officials and that they are more and more influenced by the many advantages to be gained by the use of electric lighting. Planters find now that it is much to their gain in a financial way. In former years, for example, the facilities of shipping their produce were restricted, and the work was done in daylight and slowly. Now with weekly and almost daily sailings, it is an absolute necessity that they should get their produce ready with the quickest despatch possible, and this they do with the aid of the electric light. When an engineer is called upon to install or take charge of an electric light plant, it will be well for him to insist pretty closely not only that all the materials specified in the estimates have been shipped, but that every class of tool requisite for constructional work is included. Much time is lost and much trouble is made when you find that your outfit does not include "climbing spurs" or draw vises and other important articles. I have known engineers who have had expensive testing sets, Wheatstone bridges, reflecting galvanometers and other delicate instruments sent out with them, and then found that they had few or any tools to work with, and that the nearest hardware store was many miles away through a rough country, and even then, the store when reached did not contain the requisite goods, there having been no stock kept because there was no demand made for them. Spare armatures, complete sets of arc lamp apparatus as well as duplicate parts of dynamos, spare brasses and gear for engines and tubes for boilers should always be included and it should be seen that they are shipped.

Apart from the vicissitudes incidental to life in the tropics, there is, I think, always a satisfaction and pleasure in the successful completion of an installation, knowing as one does that it is a

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potent factor in the greater civilization of those countries, demonstrating to the inhabitants, who have heretofore depended on artificial illumination of the same primitive character and manner as their forefathers used through ages past, what science aided by her lieutenants "pluck and energy" can accomplish.

DISCUSSION.

PROF. THOMSON:—Gentlemen of the Institute, you have heard the very interesting paper read and it is now open for discussion. Any remarks or additions to the information given in the paper will be acceptable from any member who has had similar experience.

I would simply say on our own account that we have had at least the effects of some of the difficulties brought home to us in the shape of corrosion in the tropical regions, on the Isthmus and especially in Colon. The wind seems to bear salt spray with it from the Gulf and it deposits this upon everything, so that brass will not live, and even copper will not live. The moisture is so great and probably salty, combined with rank vegetative emissions or effluvia, that corrosion goes on at an inconceivably rapid rate—a rate which is to us altogether unknown. I have seen brass castings partly eaten through, and even copper wire covered with insulation—not of course a very fine insulation—but I have seen the insulation partly intact and the copper wire turned into a green compound until it was nearly corroded away. I have seen lengths of it of several feet. So that we in this climate hardly appreciate the difficulties which are added to the difficulties of getting labor and commanding it as pointed out in the very interesting paper.

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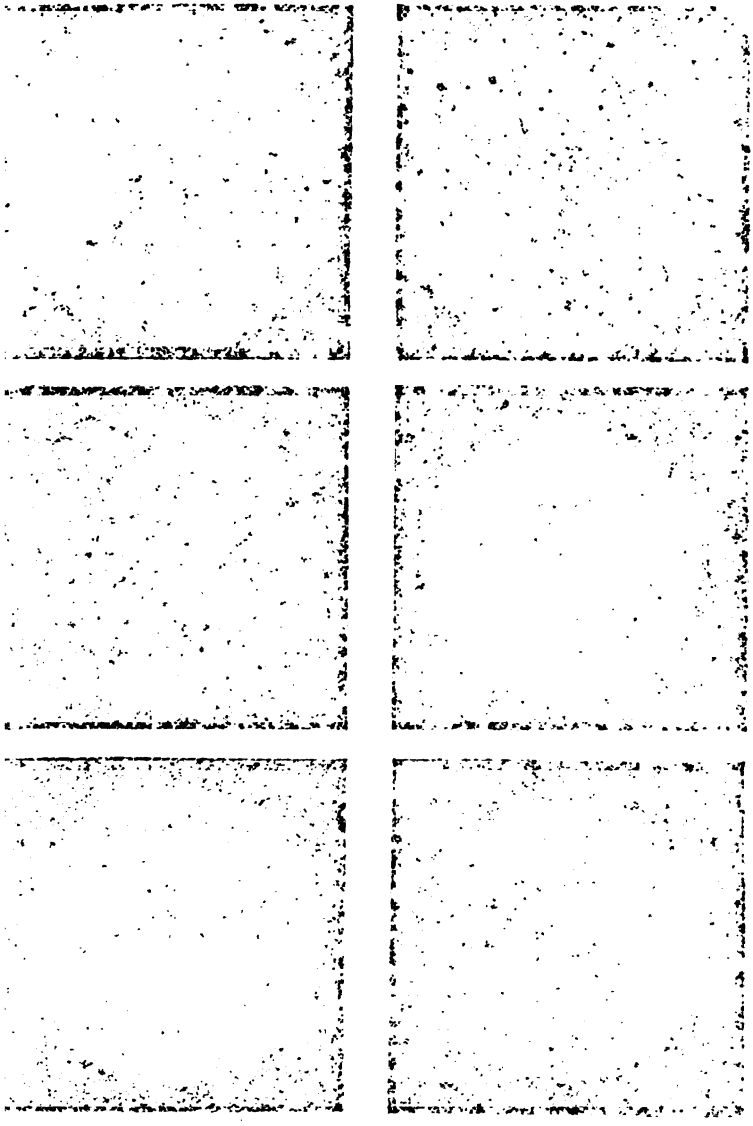

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*Read before the General Meeting of the American Institute of Electrical Engineers, Boston, May 21st, 1890.*

# LIFE AND EFFICIENCY OF ARC LIGHT CARBONS

BY LOUIS B. MARKS, M. E.

From the experimental stage of arc lighting to the commercial application of the system to-day, little or no increase in the efficiency of the carbon points appears to have been made.

Now that our dynamos and lamps have reached such a state of perfection, the subject presents itself as pre-eminently important. The arc light pencil, considered as an individual part of the plant, is indeed a small thing, but in it undoubtedly lies the weak spot of the system.

It was with a view of studying the action of modern carbon pencils, that the investigations here to be be described were undertaken. The carbons experimented upon were all of American manufacture, and were procured from five companies, (A, B, C, D and E.)

While the greater part of the research was upon the life and efficiency of the pencils, observations were also made in other directions.

The subject will be treated under the following heads:—

1st. Structure of the carbons.

2nd. Life tests.

3rd. Efficiencies.

4th. Candle-power measurements.

5th. Observations of the arc and carbon points.

It is well known that the life and efficiency of a carbon depends upon the system in which the latter is burned. For instance, "the requirement of the low tension system seems to be a carbon that is hard, well plated and a good conductor, the latter being the most important."

"In the high tension system, on the contrary, hardness and conductivity seem to be of secondary importance. There is a

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tendency to 'flame' and burn unsteadily when a hard carbon is used in this system, and a softer one sometimes becomes necessary."[1]

It is interesting to note the methods employed by carbon manufacturers to attain the conditions above mentioned. In one of our largest carbon works, "forced" carbons, or those made by "squirting" the plastic material through a die, are manufactured for both high and low tension systems of lighting, to the exclusion of molded pencils. On the other hand, another company makes no forced carbons, but claims that its molded pencils are superior for either system. From the classification given below, can be seen the types of carbons now upon the market for both systems.

| Carbon. | High tension. | Low tension. |
|---|---|---|
| A | molded | forced |
| B | " | molded |
| C | " | " |
| D | forced | forced |
| E | molded / forced | " |

One of the first things that suggested itself was the study of the structure of the various samples submitted.

For this purpose, thin transverse sections of all the specimens were cut and mounted on glass slides, and a microscopical examination made.

The accompanying photographs (Figs. 1-12) show the appearance of the carbons under a magnifying power of about forty diameters in the case of groups A, B and C, and about eighty diameters in that of D and E. While the views cannot give either the color or lustre of the original, they are mainly useful in conveying an idea of the texture of the surface.

Examining the photographs we note that there is a marked difference between the structure of a molded and a forced carbon In the high tension pencil of the brand A, (Fig. 1) the structure is a loose one, while the low tension rod of the same group is marked by a dense homogeneous structure; the size of the grains of carbon in the latter case is very much less than in the former, and as seen under the magnifying power of the microscope, the particles have a more metalloid lustre. Again there is probably considerable air space in Fig. 1.

[1] G. W. Parker: Proceedings National Elec. Light Assoc'n, Pittsburgh Convention, Feb., 1888, p. 455.

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Thus it appears that Fig. 1 has the qualifications of a high tension carbon, *i. e.* looseness of structure, hence comparative softness and high resistance; and Fig. 2 the requisites of a low tension pencil, *i. e.* density, hardness and low resistance. The resistance of the rod (Fig. 1) was measured and found equal to .199 ohm; that of Fig. 2 equalled .144 ohm. The resistance of the plated low tension carbon was .084 ohm.

The structure of the carbons in group B, (Figs. 3 and 4) was was found after close examination to be about the same. To secure the requisite low resistance of Fig. 4 the pencil was heavily copper-plated, the thickness of the coating being about 1-10 millimetre, while that of Fig 3 was a little less than 1-20 millimetre.

A method different than either of those just described is used in the manufacture of carbons C, (Figs. 5 and 6.) As in the previous instance, molded carbons are made by this company for both high and low tension systems, but a much greater pressure is applied to the molds in manufacturing low tension pencils than in the case of high. This accounts for the difference in structure exhibited in the photographs; although a molded carbon, Fig. 6 thus approaches the structure of the forced pencil, Fig. 2.

Groups D and E are highly magnified. An attempt has been made to manufacture a carbon that will burn fairly well in either system. Fig. 8 shows this carbon. In structure it is a mean between Fig. 7 and Fig. 9. Besides a difference in pressure used in constructing pencils of group D, there is also a difference in the "mix" or composition of the carbon.

The dissimilarity in structure between carbon E, Fig. 11 and E, Fig. 12 is apparent, yet both pencils are used in high tension systems. The efficiency of these types, as well as of the others will be discussed later. Fig. 12, it will be noted, is very similar in structure to Fig. 9 (carbon D); in both cases the striations are marked and indicate that the carbon is built up of strata lying longitudinally, or in the same direction as the application of the pressure used in manufacturing the pencils. When examined with the microscope, carbon D, (Fig. 9) evinced more lustre than Fig. 12, showing that a greater quantity of pure carbon was used in the manufacture of the former.

## Life Tests.

If a carbon is burned with a small current its life will be long at a sacrifice of light-giving properties. If on the other hand a

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large current is used, there may be a gain in efficiency at a sacrifice of life. The question arises—what is the proper current to use? Of course circumstances determine to a large extent the answer and generally such a current is used as gives a fair mortality at a reasonable efficiency of the carbon.

The high tension carbons submitted for test were designed to be burned at about 10 ampères and the low tension at about 20. In the life tests a Thomson lamp was used for high tension runs, current being kept constant at 10 amperes and P. D. at 50 volts. For low tension carbons the Weston lamp was used. The pencils were accurately weighed before and after the runs, and the life calculated on the assumption that the carbons were homogeneous. Each set of pencils was burned an hour. The results of tests are given in table 1.

TABLE 1.

LIFE TESTS.

| CARBON. | Mean Diameter; inches. | Resis. ohms. | Initial wt. + grms. | Initial wt. − grms. | C. amperes. | P. D. volts. | Loss in wt. + grms. | Loss wt. − grms. | Life 12 inch + carbon hours. |
|---|---|---|---|---|---|---|---|---|---|
| A molded high ten. (naked) | .502 | .199 | 59.87 | 25.10 | 10. | 50 | 5.86 | 3.59 | 10.22 |
| A forced low ten. (plated) | .500 | .072 | 64.89 | 27.16 | 21.5 | 30 | 6.15 | 4.43 | 10.55 |
| B molded high ten. (plated) | .505 | .075 | 58.17 | 28.32 | 10. | 50 | 4.80 | 2.44 | 12.12 |
| B molded low ten. (plated) | .498 | .071 | 367.80 | 295.50 | 22.5 | 28 | 166.60 | 51.50 | 9.42[2] |
| C molded high ten. (naked) | .510 | .2165 | 62.94 | 29.63 | 10. | 50 | 6.21 | 3.63 | 10.13 |
| C molded low ten. (plated) | .515 | .0715 | 594.40 | 294.50 | 22.5 | 28 | 151.00 | 41.0 | 9.83[2] |
| D forced low ten. (plated) | .506 | .095 | 62.46 | 36.10 | 21.5 | 30 | 6.92 | 3.08 | 9.03 |
| D forced high or low ten. (plated) | .504 | .142 | 60.58 | 29.78 | 10. | 50 | 6.65 | 4.16 | 9.11 |
| D forced high ten. (naked) | .457 | .187 | 47.20 | 23.53 | 10. | 50 | 5.46 | 3.29 | 8.64 |
| E forced low ten. (naked) | .505 | .2207 | 344.68 | 244.64 | 22.5 | 28 | 193.18 | 74.42 | 7.71[2] |
| E molded high ten. (naked) | .533 | .202 | 63.30 | 30.48 | 10. | 50 | 6.09 | 3.04 | 10.39 |
| E forced low ten. (naked) | .522 | .251 | 59.62 | 29 81 | 10. | 50 | 5.91 | 3.52 | 10.09 |

[2] These low tension runs were made with the Weston plant on the University Campus. Ten lamps were run in series. Time of test was 2¼ hours in the case of carbons B and E, and 2 hours and 25 min. in the case of C.

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It has been stated that "with carbons of the same *hardness* and length but having different diameters, the larger will undoubtedly outlive the smaller. Of carbons of the same *diameter* and length, but differing in hardness, the harder will outlive the softer."[1]

This statement presupposes that the conductivity of the carbon is directly dependent on the hardness or softness of the pencil.

In order to examine more fully the relation between diameter resistance and mortality of a pencil, six sets of carbons of the brand B., varying in diameter from $\frac{1}{2}$ to $1\frac{1}{5}$ inches were carefully weighed, their resistances measured by the Wheatstone Bridge method and the pencils burned with a constant current of 10 amperes from a Gramme dynamo. the P.D. at the terminals of the the lamp being kept at 50 volts. The diameters and resistances respectively of the upper and lower carbons were in each case practically the same. A mean of ten micrometer measurements of the diameter, was taken as correct. The duration of each run was 60 minutes.

Following are the data:

TABLE 2.

MORTALITY WITH DIFFERENT DIAMETERS.

| CARBON. | Mean Diameter; inches. | Resis. ohms. | Initial wt. + grms. | Loss wt. + grms. | Life 12 inch + carbon hours. |
|---|---|---|---|---|---|
| B molded high ten. | .453 | .0805 | 44.70 | 4.20 | 10.64 |
| " " | .505 | .075 | 58.17 | 4.80 | 12.12 |
| " " | .618 | .0735 | 94.98 | 6.96 | 13.64 |
| " " | .739 | .0615 | 132.34 | 6.19 | 21.38 |
| " " | .936 | .061 | 232.20 | 8.88 | 26.15 |
| " " | 1.195 | .059 | 339.57 | 10.14 | 33.49 |

From the results given in table 2, it appears that the life of a carbon varies *directly* with its *diameter* and *inversely* with its *resistance*. This law holds only for homogeneous carbons of the same manufacture, type and structure, and as stated before, for constant current and voltage.

Let us take the $\frac{1}{2}$ inch (.505″) and 1 inch .986″) pencils as standards

[1] G. W. Parker.

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and from the relation above stated, calculate the mortality of the other carbons.

Table 3 gives a comparison of the actual and the calculated life of the various specimens tested.

TABLE 3.

| Carbon. | Mean Diam. inches. | Standard—½" (.505") | Standard 1" (.986") | Actual life hours |
|---|---|---|---|---|
| | | Calculated life hours. | Calculated life hours. | |
| B molded light. | .453 | 10.92 | 9.32 | 10.64 |
| " " | .618 | 15.10 | 13.62 | 13.64 |
| " " | .789 | 21.58 | 19.44 | 21.38 |
| " " | 1.195 | 36.40 | 33.04 | 33.49 |

Thus it appears that the calculated life throughout the series is larger than the actual when the ½" carbon is taken as a standard and smaller when the 1" pencil is made the basis of calculation.

The carbons of group B were not perfectly round, a variation of 3% being at times found, between the ten measurements of the diameter of a pencil. In determining the resistance of the carbon rods, the tips of the latter were copper-plated when necessary and mercurial contacts used. The lamp was adjusted to burn at 50 volts potential difference for each set of pencils.

While every precaution was taken to avoid discrepancies, it is clear that from the nature of the substance experimented upon, and the extreme difficulty of maintaining constant conditions, errors are apt to creep into the work. But the results given in table 3 as well as later determinations undoubtedly point to the existence of such a law as has been quoted.

The relation between diameter and life having been investigated, experiments were then made to determine the curve for current and mortality of the pencil, when the voltage is kept constant.

For this purpose a number of molded high tension carbons of the brand E were used. To secure uniformity in the plus and minus pencils, a 12 inch stick was broken in half, one portion being used as the upper, the other as the lower carbon. The length of each run was an hour. Current and potential were read every two minutes and the mean taken.

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Table 4 gives the data from which the curve for current and mortality (Fig. 3) was plotted.

TABLE 4.

LIFE WITH DIFFERENT CURRENTS AND CONSTANT POTENTIAL.

| Carbon. | Diam. mean inches. | Resis. ohms. | Initial wt.+ grms. | Initial wt.— grms. | C. amp. | P. D. volts. | Loss wt.+ grms. | Loss wt.— grms. | Life per inch Carbon burned hours. | $\left\{\frac{\text{Life}-}{\text{Life}+}\right\}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| E molded high ten. | .518 | .199 | 30.20 | 21.15 | 6.02 | 49.3 | 4.48 | 2.77 | .6723 | 1.62 |
| " | " | " | 25.72 | 18.38 | 7.04 | 49.7 | 4.87 | 3.19 | .6047 | 1.54 |
| " | " | " | 20.85 | 15.19 | 8.01 | 49.9 | 5.42 | 3.25 | .5622 | 1.66 |
| " | " | " | 37.56 | 24.16 | 8.99 | 49.9 | 5.81 | 3.63 | .5450 | 1.60 |
| " | " | " | 31.75 | 20.58 | 10.01 | 49.3 | 6.16 | 3.98 | .5072 | 1 52 |
| " | " | " | 30.52 | 21.72 | 11.00 | 50.2 | 6.67 | 4.18 | .4910 | 1.60 |
| " | " | " | 34.30 | 26.90 | 12.08 | 50.3 | 6.65 | 4 35 | .4637 | 1.52 |
| " | " | " | 37.78 | 26.33 | 13.00 | 50.1 | 7.26 | 4.61 | .4502 | 1.57 |

As will be seen the range of current was from 6 to 13 amperes. The greatest variation of the mean E. M. F. for the several runs was one volt.

TABLE 5.

LIFE WITH DIFFERENT POTENTIALS AND CONSTANT CURRENT.

| CARBON. | Mean Diam; inches. + | Mean Diam; inches. — | Resis. ohms. | Initial wt. + grms. | Initial wt. — grms. | C. amperes. | P. D. volts. | Loss wt. + grms. | Loss wt. — grms. | Life per inch Carbon burned, hours. | $\left\{\frac{\text{Life}-}{\text{Life}+}\right\}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| E molded high ten. | .513 | .513 | .199 | 51.58 | 48.32 | 10 | 40 | 5.625 | 2.32 | .6425 | 2.344 |
| " | .521 | .517 | .197 | 37.65 | 24.16 | 10 | 45 | 5.605 | 2.87 | .6077 | 1.958 |
| " | .531 | .522 | .185 | 24.86 | 19.06 | 10 | 50 | 5.83 | 3.49 | .5453 | 1.693 |
| " | .531 | .522 | .185 | 24.86 | 19.06 | 10 | 55 | 6.34 | 4.025 | .4903 | 1.589 |
| | .527 | .530 | .191 | 23.52 | 19.34 | 10 | 60 | 6.70 | 4.41 | .4525 | 1.484 |

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A series of tests was now made with constant current and varying voltage. The current in this case was maintained at ten amperes, and the range in tension was from forty to sixty volts. Carbons of the same type as in the last instance were used. In table 5, are given the figures for these runs and Fig. 14 shows the curve for voltage and mortality.

In the curves (Figs. 13 and 14). the ordinates represent the life of an inch of carbon in minutes. Reference is made not to the mortality of the plus pencil, but to the total amount of carbon burned in the lamp. The last two columns in Table 5, have been corrected for diameter and resistance of the pencil, the diameter and resistance respectively of the carbon that was burned at 10 amperes and 45 volts having been taken as a standard, and the life of the other pencils reduced to a common basis from this, according to the law previously stated.

Very little has been published regarding the relative life of the plus and minus carbons. Those books in which the subject is alluded to, state as a rule that with direct currents, the life of the upper carbon is about half that of the lower, provided both have the same length originally. In a recent publication [1] the general statement is made that "with continuous currents the plus wastes twice as fast as the minus carbon. With alternating currents the upper wastes 8 per cent. faster than the lower if the carbons are vertical; but at the same rate if horizontal."

TABLE 6.

RELATIVE LIFE OF THE PLUS AND MINUS CARBONS.

| CARBON. | Initial wt. + grms. | Initial wt. − grms. | C. ampere. | P. D. volts. | Length run; minutes. | Loss wt. + grms. | Loss wt. − grms. | $\left\{\frac{\text{Life } 1'-}{\text{Life } 1'+}\right\}$ |
|---|---|---|---|---|---|---|---|---|
| B molded high ten. | 48.38 | 25.22 | 10 | 50 | 60 | 5.28 | 4.40 | 1.20 |
| B molded low ten. | 61.43 | 31.37 | 10 | 50 | 60 | 5.14 | 3.27 | 1.57 |
| A molded high ten. | 90.57 | 38.68 | 10 | 50 | 60 | 5.98 | 3.20 | 1.87 |
| 10 E forced low ten | 344.68 | 244.64 | 22½ | 28 | 150 | 193.18 | 74.42 | 2.59 |
| 10 B molded low ten. | 367.80 | 259.50 | 22½ | 28 | 150 | 166.60 | 51.50 | 3 23 |
| 10 C molded low ten. | 594 40 | 294.50 | 22½ | 28 | 145 | 151.00 | 41.00 | 3.68 |

[1] Munro & Jamiesons' Electrical Rules and Tables, 1889.

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No experiments were made upon arc-light carbons fed by alternating currents but an investigation of the relative loss of the plus and minus pencils with direct currents gave quite interesting results. Table 6 shows that the plus carbon may burn away about as fast as the minus, or may waste more than three and a half times as quickly.

Three sets of experiments were undertaken to determine the elements that affect this ratio.

First. Effect of changing the diameter and resistance of the pencils with constant current and potential.

Second. Influence of change of current with constant potential.

Third. Change of potential with constant current.

For determining the influence of diameter and resistance upon the relative life of the plus and minus carbons, a number of molded high tension pencils of the brand A were used. The carbons were supposed to have been taken from the same "batch" and were burned with a current of 10 amperes and a P. D.=50 volts.

Examining table 7, which gives the results of measurements we note that $\left\{\frac{\text{life}-}{\text{life}+}\right\}$ appears to become greater with increase of diameter of the carbon. It is probable that the inequality in the diameters of the + and — pencils respectively, as well as the difference in the resistances of the two carbons of a set explains to a large extent the cause of this increase in the ratio. For assuming that under the conditions maintained, the life of a carbon varies directly with its diameter and inversely with its resistance, the data, (Table 7) indicate that if the diameters and resistances respectively of the + and — carbons were the same in each run, the ratio would be practically the same for all sizes of carbons. This is brought out in the last column of the table, which gives the corrected values of $\left\{\frac{\text{life}-}{\text{life}+}\right\}$

Second. Reference to the last column of Table 4 will show that a change in the current, other conditions remaining the same, probably has no effect on the ratio $\left\{\frac{\text{life}-}{\text{life}+}\right\}$. For when a current of 6 amperes was used, the ratio was equal to 1.62; at 7 amperes the ratio dropped to 1.54; it then alternately increased and decreased to 13 amperes. Hence it may be said that if all

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TABLE 7.

INFLUENCE OF DIAMETER AND RESISTANCE OF THE CARBON UPON THE RELATIVE LIFE OF THE + AND — PENCILS.

| CARBON. | Mean diam. inches. + | Mean diam. inches. — | Resis. Ohms. + | Resis. Ohms. — | Initial wt. + | Initial wt. — | Loss wt. + | Loss wt. — | $\left\{\frac{\text{Life } 1' -}{\text{Life } 1' +}\right\}$ | $\frac{\text{Life } 1' -}{\text{Life } 1 +}$ corrected |
|---|---|---|---|---|---|---|---|---|---|---|
| A molded high ten. | .3964 | .4083 | .255 | .240 | 37.91 | 16.97 | 4.96 | 3.04 | 1.68 | 1.79 |
| " | .4567 | .4567 | .225 | .243 | 48.98 | 20.26 | 5.41 | 3.2[illegible] | 1.65 | 1.78 |
| " | .5018 | .5153 | .199 | .207 | 59.87 | 25.10 | 5.86 | 3.59 | 1.68 | 1.74 |
| " | .5698 | .5622 | .178 | .190 | 69.83 | 26.91 | 6.23 | 3.61 | 1.73 | 1.81 |
| " | .6311 | .6268 | .152 | .149 | 90.57 | 38.68 | 5.98 | 3.20 | 1.87 | 1.83 |

errors of observation, as well as those due to irregularities in the carbons could be eliminated, the $\frac{\text{life} - \text{carbon}}{\text{life} + \text{carbon}}$ would be found to be constant.

THIRD. The last column of Table 5 contains the data for $\frac{\text{life} -}{\text{life} +}$ with different P. D.'s and constant current. From these calculations it appears that the ratio depends on the P. D. and that the greater the P. D., the more nearly does the former approach unity. The curve plotted from the figures in table 5, is given in Fig. 15, the abscissæ being volts, and the ordinates representing the ratio of the life of the minus to the life of the plus carbon.

Thus the causes that influence the relative life of pencils of the same diameter, lie chiefly in the difference in the resistance of the carbons and the variations of P. D.

Judging from existing theories of the arc, it was thought that blowing the latter with a magnet during the runs would relatively increase the life of the plus carbon. The experiment was tried and the reverse was found to take place, *i. e.*, the ratio $\left\{\frac{\text{life} -}{\text{life} +}\right\}$ increased while the life of the minus pencil was not much affected.

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## Efficiencies.

Two methods of determining the efficiency of each set of pencils were employed. The first was the method used by Mr. Merritt in obtaining the efficiency of the incandescent lamp[1] and subsequently by Mr. Nakano in his work on the efficiency of the arc-lamp[2]. The second dealt with candle-powers and will be referred to in the discussion of candle-power measurements.

It may not be amiss to give here an outline of the first method employed. A Thomson lamp was mounted on a movable frame and the rays from the burning carbons allowed to fall on the face of a thermo-pile, the latter being in circuit with a sensitive Thomson galvanometer. The deflection of the galvanometer was taken as a measure of the energy of the total radiation which fell upon the face of the pile. A cell containing a solution of alum was then interposed between the light and the pile, and the reduced deflection of the galvanometer noted. On the supposition that the alum cell cut off all the "dark heat" and allowed only the rays of the visible spectrum to reach the face of the thermo-pile, the last measurement would give the true value of the luminous energy emitted by the lamp. But a small percentage of the longer wave lengths passes through the alum cell, and a large part of the luminous rays is cut off by its intervention. Corrections having been made for these factors, the true values of luminous radiation resulted.

A mechanism was provided by which measurements could be made at various angles below the horizontal plane without altering the distance between the center of the arc and the thermo-pile.

For the high tension runs, the lamp was fed by a current of 9 amperes, the potential difference between its terminals being kept at 45 volts. For low tension tests, current — 21½ amperes, and P. D. — 30 volts. Note that the amount of energy expended in the low tension lamp was $21\frac{1}{2} \times 30 = 645$ watts, while the high tension required but $9 \times 45 = 405$ watts. Although normally the former requires from 520 to 560 watts, unsteadiness of the light when the lamp was run below 21½ amperes made accurate measurements impossible.

Tables 8-15 give the results of efficiency tests. In the column

[1] E. G. Merritt: Some Determinations of the Energy of the Light from Incandescent Lamps. Amer. Jour. Science. Vol. 37. p. 167.

[2] H. Nakano: Efficiency of the Arc Lamp; Transactions Amer. Inst. Elec. Eng. Vol. VI, p. 308.

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## EFFICENCY MEASUREMENTS.

TABLE 8.

CARBON A. MOLDED HIGH TENSION.

| Angle. | L | T | $\frac{L}{T}$ |
|---|---|---|---|
| 0° | 6.085 | 110 | .0553 |
| 10° | 8.112 | 130 | .0624 |
| 20° | 11.49 | 134 | .0858 |
| 30° | 16.90 | 146 | .1158 |
| 40° | 23.67 | 146 | .1621 |
| 50° | 15.55 | 143 | .1087 |
| 60° | 10.14 | 125 | .0811 |

TABLE 9.

CARBON D. FORCED HIGH TENSION.

| Angle. | L | T | $\frac{L}{T}$ |
|---|---|---|---|
| 0° | 4.733 | 107 | .0442 |
| 10° | 8.133 | 118 | .0688 |
| 20° | 11.49 | 129 | .0891 |
| 30° | 14.20 | 142 | .0977 |
| 40° | 16.91 | 152 | .1112 |
| 50° | 19.61 | 156 | .1257 |
| 60° | 8.790 | 142 | .0619 |

TABLE 10.

CARBON B. UNPLATED MOLDED HIGH TEN.

| Angle. | L | T | $\frac{L}{T}$ |
|---|---|---|---|
| 0° | 10.14 | 114 | .0889 |
| 10° | 13.52 | 127 | .1065 |
| 20° | 15.55 | 144 | .1080 |
| 30° | 18.26 | 157 | .1163 |
| 40° | 22.31 | 165 | .1352 |
| 50° | 22.31 | 163 | .1352 |
| 60° | 15.55 | 156 | .0995 |

TABLE 11.

CARBON B. PLATED MOLDED HIGH TEN.

| Angle. | L | T | $\frac{L}{T}$ |
|---|---|---|---|
| 0° | 11.49 | 116 | .0991 |
| 10° | 14 21 | 128 | .1057 |
| 20° | 15.55 | 145 | .1072 |
| 30° | 19.60 | 157 | .1248 |
| 40° | 22.31 | 164 | .1361 |
| 50° | 18.93 | 164 | .1369 |
| 60° | 15.55 | 141 | .1103 |

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TABLE 12.

CARBON E. MOLDED HIGH TENSION.

| Angle. | L | T | $\frac{L}{T}$ |
|---|---|---|---|
| 0° | 2.702 | 116 | .0233 |
| 10° | 5.405 | 134 | .0408 |
| 20° | 8.108 | 146 | .0555 |
| 30° | 13.51 | 157 | .0861 |
| 40° | 17.57 | 159 | .1105 |
| 50° | 11.48 | 145 | .0792 |
| 60° | 7.77 | 112 | .0710 |

TABLE 13.

CARBON E. FORCED HIGH TENSION.

| Angle. | L | T | $\frac{L}{T}$ |
|---|---|---|---|
| 0° | 2.702 | 118.5 | .0228 |
| 10° | 4.054 | 131 0 | .0310 |
| 20° | 6.756 | 158. | .0428 |
| 30° | 6.081 | —— | .0483 |
| 40° | 10.13 | 175.0 | .0579 |
| 50° | 14.19 | 155.0 | .0895 |
| 60° | 11.48 | 136.0 | .0844 |

TABLE 14.

CARBON A. FORCED LOW TENSION.

| Angle. | L | T | $\frac{L}{T}$ |
|---|---|---|---|
| 0° | 8.784 | 163 | .0542 |
| 10° | 12.16 | 170 | .0715 |
| 20° | 20.27 | 185 | .1095 |
| 30° | 25.68 | 190 | .1351 |
| 40° | 25.68 | 190 | .1351 |
| 50° | 16.89 | 157 | .1080 |
| 60° | 9 459 | 130 | .0728 |

TABLE 15.

CARBON B. MOLDED LOW TENSION.

| Angle. | L | T | $\frac{L}{T}$ |
|---|---|---|---|
| 0° | 10.81 | 190 | .0569 |
| 10° | 17.57 | 211 | .0833 |
| 20° | 25.68 | 223 | .1151 |
| 30° | 28.38 | 223 | .1273 |
| 40° | 17.57 | 215 | .0817 |
| 50° | 12.33 | 182 | .0678 |
| 60° | 6.081 | 135 | .0451 |

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headed (L) are given the corrected values of deflections due to luminous radiation; the values of (T) refer to total radiation and the efficiency or luminous divided by total radiation — $\left\{\frac{L}{T}\right\}$.

These tables furnish the date from which the curves (Figs. 16-23 were plotted. The radii show the positions for which measurements were taken and distances measured along these lines from the origin to the *dotted* curves, give the intensity of luminous and total radiation respectively in each position.

It will be seen that the distribution of total radiation differs considerably from that of luminous radiation hence the efficiency, which is expressed by $\left\{\frac{\text{luminous radiation}}{\text{total radiation}}\right\}$ depends upon the angle of measurement.

The full-line curves (Figs. 16-23) represent the efficiencies of the various carbons. In order to obtain the mean or hemispherical efficiency, the areas of the curves of luminous and of total radiation were found by means of the planimeter; now the ratio of the radii of two semi-circles whose areas are respectively equal to those of the curves of luminous and total radiation, is the value of the mean spherical efficiency. This value has been calculated for each set of pencils and the results are given in Table 16; also in Figs. 16-23.

TABLE 16.

EFFICIENCY MEASUREMENTS.

| CARBON. | Diam. mean inches. | Resis. ohms. | C. amp. | P. D. volts. | Horizontal efficiency. | Maximum efficiency. | Hemi-spherical efficiency. | Life 12 inch + carbon hours. C. / P. D. |
|---|---|---|---|---|---|---|---|---|
| A molded high ten. | .508 | .203 | 9 | 45 | .0553 | .1621 | .1171 | 10.22(10 -50) |
| D forced high ten. | .457 | .187 | 9 | 45 | .0442 | .1257 | .1001 | 8.64(10 -50) |
| B molded (unplated) high ten. | .453 | .224 | 9 | 45 | .0889 | .1352 | .1269 | 9.16(10 -50) |
| B molded (plated) high ten. | .453 | .0805 | 9 | 45 | .0991 | .1369 | .1272 | 10.64(10 -50) |
| E molded high ten. | .538 | .202 | 9 | 45 | .0233 | .1105 | .0896 | 10.39(10 -50) |
| E forced high ten | .522 | .251 | 9 | 45 | .0228 | .0895 | .0776 | 10.09(10 -50) |
| A forced low ten. | 500 | .072 | 21.5 | 30 | .0542 | .1351 | .1105 | 10.55(21½-30) |
| B molded lowten. | .498 | .071 | 21.5 | 30 | .0569 | .1273 | .0982 | 9.42(22½-28) |

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We notice that the horizontal efficiency is very small compared with the maximum; that relatively high efficiency in a *forced high tension* carbon is obtained only at the expense of life; that a *molded* carbon is, generally speaking, superior to a *forced* for high tension and vice versa for low tension.

In the case of the high tension carbons B and D, the diameters are smaller than those of the other pencils, hence we are to expect a relatively higher efficiency since as was shown last year, the "efficiency varies inversely as the diameter."[1]

A point of interest brought out by these tests (Tables 10 and 11 and Figs. 18 and 19), is the fact that while the life of a copper plated carbon is greater than that of an unplated carbon of the same diameter and type, the mean spherical efficiency appears to be the same for both.

Two sets of pencils of the brand (B), the one unplated and the other plated, were burned to ascertain this relation. The results show that the horizontal and the maximum efficiency of the copper-plated carbons were a little greater than those of the uncoated pencils respectively, and the mean spherical efficiency in the latter case was very slightly less than in the former. As can be seen from Table 16, the life of the "positive" plated pencil (12″ long) was 10.64 hours, while that of the naked carbon was 9.16 hours, the current and P. D. having been the same for both cases.

No positive explanation of this phenomenon has yet been given but it appears that the actual amount of *combustion* in both cases is the same while the *disintegration* caused by the passage of the current is greater in the case of the unplated carbon.

### Candle Power Measurements.

The candle-power measurements consisted chiefly in the determination of the hemi-spherical candle-power of the different pencils and from this quantity, the watts per spherical candle-power produced.

The runs were made under the same conditions as in the efficiency tests. For high tension carbons current = 9 amperes and P. D. = 45 volts. For low tension pencils, current = 21.5 amperes and P. D. = 30 volts.

To ascertain the candle-powers, the method of the Franklin

[1] H. Nakano.

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Institute Committee was used.[1] The photometric apparatus was somewhat different in detail from that ordinarily used in measuring the candle-power of incandescent lamps and deserves a brief description.

The arc-lamp was suspended from an arm which could be rotated about an axis parallel to the photometer bar and vertically above it. By manipulating a rope connected with the arm, the latter could be raised until it was at right angles with the photometer-bar, or lowered until it was horizontal. The arm being horizontal, the lamp was hung from its extremity so that the arc was on a level with the center of the photometer-disc. It will be seen that when the arm was pulled up, the arc described a vertical circle, the axis of which was a line parallel to the photometer-bar and passing through the center of the disc. The centre of the vertical circle was at the point (800) of a scale graduated into (1,000) divisions, and the radius equal to the length of (200) scale divisions.

At the zero of the scale was placed a Weston incandescent lamp, and a circular mirror of silvered glass, the axis of which was horizontal and inclined 45° to the reflecting surface, was mounted on the bar so that its centre coincided exactly with the 800th division of the scale. Thus the distance between the arc-lamp and the mirror was rendered constant for all elevations of the former, and when the mirror reflected the light of the lamp upon the disc, the angles of incidence and reflection were always equal to 45°. The virtual image of the arc under these circumstances was at the 1000th division of the scale. The Weston lamp was used as a secondary standard and maintained by a storage battery throughout the runs at 115 volts; its candle-power was ascertained before and after the tests by comparing it with a standard Methven "Board of Trade" 2 c. p. slit.

Photometer readings were made as in the case of the efficiency tests, at 0° and at 10°, 20°, 30°, 40°, 50°, and 60°, below the horizontal, the mean of twenty observations being taken for each elevation. These measurements were multiplied by the candle-power of the secondary standard and corrected for absorption of light by the mirror.

Tables 17-23 gives the corrected data, which form the basis of the candle-power, curves (Figs. 24 and 25). Distances mea-

[1] Reports; International Electrical Exhibition of Franklin Inst. 1884. Group B, Sections V and VIII.

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sured along the radii from the origin to each curve, give the candle-power for the various angles. The mean spherical candle power for any case is measured by the radius of a semi-circle whose arc is equal to the area of the c. p. curve.

CANDLE POWER MEASUREMENTS.

| TABLE 17. Carbon A; molded high tension. | | TABLE 18. Carbon B; molded high tension. | | TABLE 19. Carbon D: forced high tension. | | TABLE 20. Carbon E; molded high tension. | |
|---|---|---|---|---|---|---|---|
| Angle. | Candle-power. | Angle. | Candle-power. | Angle. | Candle-power. | Angle. | Candle-power. |
| 0° | 221.3 | 0° | 382.2 | 0° | 210.5 | 0° | 227.3 |
| 10° | 474.1 | 10° | 638.4 | 10° | 407.4 | 10° | 288.8 |
| 20° | 713.1 | 20° | 908.4 | 20° | 687.4 | 20° | 429.9 |
| 30° | 979.2 | 30° | 1113. | 30° | 977.1 | 30° | 722.2 |
| 40° | 1053.0 | 40° | 1131. | 40° | 1079.0 | 40° | 957.2 |
| 50° | 928.6 | 50° | 749.3 | 50° | 1140. | 50° | 1080.0 |
| 60° | 370.7 | 60° | 579.8 | 60° | 595.7 | 60° | 414.0 |

| TABLE 21. Carbon E; forced high tension. | | TABLE 22. Carbon A; forced low tension. | | TABLE 23. Carbon B; molded low tension. | |
|---|---|---|---|---|---|
| Angle. | Candle-power. | Angle | Candle-power. | Angle. | Candle-power. |
| 0° | 221.7 | 0° | 593.7 | 0° | 475.4 |
| 10° | 288. | 10° | 712.1 | 10° | 593.7 |
| 20° | 350.1 | 20° | 86 .3 | 20° | 720.9 |
| 30° | 558.9 | 30° | 1094. | 30° | 871.3 |
| 40° | 636.3 | 40° | 1183. | 40° | 866.6 |
| 50° | 630.7 | 50° | 682.2 | 50° | 528.4 |
| 60° | 235.5 | 60° | 495.4 | 60° | 354.8 |

Although great care was taken in ascertaining the candle-powers, the difference in color between the light emitted by the arc and that given by the standard was so marked that the setting of the photometer-carriage was to a large extent a matter of

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personal judgment; hence the measurements given cannot be considered as absolute, but rather as relative values.

The conclusions drawn from the efficiency curves hold generally, as will be seen by an examination of Table 24, for the candle power curves. From the latter it appears that the efficiency of low tension carbons, and especially of *molded* low tension pencils is comparatively small. While the efficiencies of molded high tension carbons are as high as .953 and .888 watts per spherical candle or 783 and 840 candles per electrical horse-power expended in the lamp, the efficiencies of low tension pencils of nearly the same diameter as the high are as small as 1.255 and 1.612 watts per candle or 594 and 502 candles per electrical horse-power.

This fact is not brought out in Table 16, for reference to the latter shows the low tension pencils to have a rather high efficiency, and in some cases considerably higher than the high tension carbons. However, when the energy expended in the lamp in the two cases respectively is taken into account, the explanation of the high values for carbons A and B (Table 16, low tension) is apparent.

TABLE 24.

CANDLE POWER MEASUREMENTS.

| CARBONS. | Diam. (mean) inches. | Resis. ohms. | C. amp. | P. D. volts. | Horizontal Candle-power. | Maximum c. p. | Hemi-spherical c. p. | Watts per spher. c. p. | Spher. c. p. per Elec. horse-power |
|---|---|---|---|---|---|---|---|---|---|
| A molded high ten. | .508 | .208 | 9 | 45 | 221 | 1053 | 456 | .888 | 840 |
| D forced high ten. | .457 | .187 | 9 | 45 | 210 | 1140 | 486 | .833 | 895 |
| B unplated molded high ten. | .458 | .224 | 9 | 45 | 382 | 1131 | 525 | .771 | 967 |
| E molded high ten. | .533 | .202 | 9 | 45 | 227 | 1080 | 425 | .953 | 783 |
| E forced high ten. | .522 | .251 | 9 | 45 | 222 | 626 | 288 | 1.407 | 531 |
| A forced low ten. | .500 | .072 | 21.5 | 30 | 594 | 1188 | 514 | 1.255 | 594 |
| B molded low ten. | .498 | .071 | 21.5 | 30 | 475 | 871 | 400 | 1.612 | 502 |

Carbon B (molded high ten., Table 24), it will be noted has the highest efficiency of the group. This is due largely to the fact

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that its diameter is smaller than that of any of the others, for "the candle-power varies inversely as the diameter."[1]

Similarly the relatively high candle-power of carbon D is accounted for by the small diameter of the pencil. In Table 24 and the candle-power curves, we again note the comparatively small efficiency of *forced* high tension carbons.

The efficiency of carbon A., (molded high tension, Table 16), as measured by $\left\{\frac{\text{luminous radiadion}}{\text{total radiation}}\right\}$ is larger than that of carbon D; yet the mean spherical candle power of the latter is greater than that of the former (Table 24). The explanation of this phenomenon (assuming the measurements to be correct) probably lies in the difference in the *quality* of the light emitted.[2]

In some instances it is desirable to ascertain the mean spherical candle-power of a lamp approximately, without taking the time to integrate the curve.

The formula given by M. Gerard, namely, "spherical c. p. = $\frac{1}{2}$ horizontal c. p. + $\frac{1}{4}$ maximum c. p."[3] is of sufficient exactitude for practical purposes. Gerard gives the following table showing the observed and calculated spherical candle-powers for seven lamps.

TABLE 25.

GERARD'S MEASUREMENTS OF CANDLE POWER.

| LAMPS. | Horizontal c. p. | Maximum c. p. | Spherical c. p. calculated. | Spherical c. p. observed. |
|---|---|---|---|---|
| No. 1 | 250 | 1464 | 491 | 470 |
| " 2 | 456 | 3250 | 1040 | 1145 |
| " 3 | 560 | 3071 | 1048 | 1221 |
| " 4 | 744 | 1227 | 679 | 692 |
| " 5 | 122 | 840 | 271 | 274 |
| " 6 | 586 | 2100 | 818 | 802 |
| " 7 | 935 | 1150 | 755 | 767 |

[1] M. Schreihage: Centralblatt für Elektrotechnik, No. 22, 1888.

[2] The reader is referred in this connection to, "A Spectrophotometric Comparison of Artificial Sources of Illumination." Paper by Edward L. Nichols and W. S. Franklin, read before A. A. A. S. at Cleveland, August, 1888.

[3] M. Gérard: Candle Power of Arc Lamps:—Centralblatt für Elektrotechnik, also N. Y. Elec. World, Jan. 25th, 1890.

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Taking the whole number of lamps, the average error is only five per cent. "The angle of maximum intensity was about 45° usually, but in some cases it approached that of 30° or 60° from the horizontal."

Data collected from various sources, including the tests of the Franklin Institute Committee in 1884, are given in Table 26. From the horizontal and maximum candle-powers, the mean spherical was calculated by Gerard's law. Comparison with the observed candle-powers shows that in some cases the error is less than one per cent. The mean error is, however, larger than that obtained by Gerard, and reaches about 9¾ per cent. Hence as was stated before, the law is valueless except in cases of rough approximation.

TABLE 26.

CANDLE-POWER CALCULATIONS, USING GÉRARDS' LAW.

| LAMPS. | Horizon. c. p. | Max. c. p. | Spherical c. p. observed. | Spherical c. p. Calculated. | Authority. |
|---|---|---|---|---|---|
| Weston | 344 | 609 | 348 | 324 | B. W. Snow. |
| " | 299 | 576 | 295 | 293 | " |
| " | 576 | 1235 | 640 | 597 | " |
| Brush | 313 | 1395 | 609 | 504 | " |
| Ball | 233 | 534 | 240 | 249 | Prof. W. A. Anthony |
| Brush (1200 c. p.) | 180 | 617 | 263 | 244 | " |
| Brush (2000 c. p.) | 389 | 1380 | 653 | 539 | " |
| Van Depoele (20 light) | 451 | 1377 | 574 | 569 | " |
| Van Depoele (60 light) | 333 | 1155 | 470 | 455 | " |
| Western Elec. | 263 | 355 | 186 | 220 | " |
| Thomson-Houston. | 227 | 1080 | 425 | 383 | L. B. Marks. |
| " " | 222 | 626 | 288 | 267 | " |
| " " | 382 | 1131 | 525 | 474 | " |
| Weston | 594 | 1183 | 514 | 593 | " |
| " | 475 | 871 | 400 | 436 | " |

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Reference has been made to the fact that while the curve for luminous radiation is similar to that of candle-power, the curve for total radiation differs widely from the latter. As the efficiency depends upon the ratio $\left\{\frac{\text{luminous radiation}}{\text{total radiation}}\right\}$ it is plain that Gerard's law will not hold for calculating the mean spherical efficiency from the horizontal and the maximum. But again, for approximations a similar law holds, *i. e.*,

$$\textit{Spherical efficiency} = \tfrac{1}{4}\ \textit{horizontal} + \tfrac{3}{4}\ \textit{maximum}.$$

Although the topic of efficiencies has been discussed in another part of the article, it may not be out of place to add a few words here, bearing upon the law in question. Measurements of horizontal, maximum and mean spherical efficiency, made by Mr. H. Nakano and by the writer, are given in Table 27, and the last law mentioned applied in the calculation of the spherical efficiency. In some cases the error is exceedingly small while in others it is comparatively large; the mean error of fourteen tests is not quite 8 per cent.

TABLE 27.

OBSERVED AND CALCULATED EFFICIENCIES.

| CARBON. | Horizon Effic. | Max. Effic. | Spherical Effic. observed. | Spherical Effic. calculated. |
|---|---|---|---|---|
| .832 inch. | 1.82% | 9.00% | 6.87% | 5.60% |
| .563 " | 4.12% | 14.41% | 11.00% | 11.88% |
| .500 " | 4.91% | 17.33% | 12.66% | 14.22% |
| .450 " | 5.48% | 15.52% | 13.30% | 13.01% |
| .370 " | 5.55% | 17.50% | 15.54% | 14.51% |
| .250 " | 8.44% | 19.80% | 16.60% | 16.96% |
| A molded high ten. | 5.53% | 16.21% | 11.71% | 13.53% |
| D forced " | 4.42% | 12.57% | 10.01% | 10.58% |
| B (unplated) " | 8.89% | 13.52% | 12.69% | 12.37% |
| B (plated) " | 9.91% | 13.69% | 12.72% | 12.75% |
| E molded " | 2.33% | 11.05% | 8.96% | 8.87% |
| E forced " | 2.28% | 8.95% | 7.76% | 7.29% |
| A forced low ten. | 5.42% | 13.51% | 11.05% | 12.68% |
| B molded " | 5.69% | 12.73% | 9.32% | 10.96% |

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### Observations of the Arc and the Carbon-points.

With a given potential difference between the terminals of the lamp, the length of the arc depends upon the current flowing, and increased as the current becomes greater. If the current be kept constant, the length of the arc increases with the P. D.

Data given in Tables 28 and 29 show the length of the arc for both cases.

TABLE 28.

Length of Arc: Constant Potential.

| Carbon. | Current amp. | P. D. volts. | Length of arc; inches. |
|---|---|---|---|
| E, molded high tension. | 6 | 50 | .087 |
| " " | 7 | " | .114 |
| " " | 8 | " | .137 |
| " " | 9 | " | .147 |
| " " | 10 | " | .150 |
| " " | 11 | " | .154 |
| " " | 12 | " | .156 |
| " " | 13 | " | .167 |

TABLE 29.

Length of Arc: Constant Current.

| Carbon. | Current amp. | P. D. volts. | Length of arc; inches. |
|---|---|---|---|
| E, molded high tension. | 10 | 40 | .078 |
| " " | " | 45 | .095 |
| " " | " | 50 | .141 |
| " " | " | 55 | .186 |
| " " | " | 60 | .216 |

In order to measure the length of the arc, a lens was so mounted as to throw the magnified image of the former upon a surface carrying a vertical scale. Then after measuring the distance between the magnified points and applying the proper reduction

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factor, an additive correction was made for the depth of the crater, thus giving the length of arc from the tip of the minus pencil to the point directly above in the center of the crater of the plus.

From the figures (Tables 28 and 29), it seems that no direct relation exists between the length of the arc and the current and P. D. In the case of the carbons tested, the length of the arc with constant potential increased very rapidly as the current was changed from 6 to 9 amperes, and then gained slowly from 9 to 13 amperes. The nature of the change was somewhat different in the constant current runs, the length of the arc increasing more nearly as the square of the voltage.

After each of the runs noted in Tables 28 and 29, the carbon-points were examined, and it was found that the latter assumed particular shapes depending upon the current and P. D. used. Another series of tests were made with carbons C. and E. (molded high ten), in which the current ranged from 5 to 15 amperes, the P. D. being kept constant at 50 volts.

Fig. 26 shows the form of the points with different currents. Nos. 1, 2 and 3 are pencils of the brand C and 4, 5, 6 and 7 of the type E. The photographs of the carbons, Fig. 27, are three-quarters of the actual size.

Examining the first three pencils, we see that with 5 amperes, there is a tendency to form a "mushroom" on the lower or negative carbon; the latter is eaten away considerably just below the tip. With 10 amperes this tendency is not at all marked and at 15, almost inappreciable.

Glancing at the upper or plus carbons, it appears that the smaller the current, the more nearly does the positive pencil burn to a point, that is, the smaller the diameter of the crater. But though the width of the crater is less in the case of low currents than with high, the depth of the former is correspondingly greater. The photographs do not bring out this point, but an inspection of the tip of the lower carbon gives a clue to the facts. Note that with small currents the negative electrode terminates in a pointed, sometimes globular projection. As has been stated before this, tip becomes less noticeable with increase of current, a fact which is brought out by inspecting Nos. 7. 6, 5 and 4 (Fig. 26.) In No. 4, burned at 15 amperes, the end of the lower carbon is blunted; the depth of the crater in the upper was practically zero. In Nos. 5, 6 and 7 burned at 12, 9 and 6 amperes respectively, the depth of the crater increases as the current diminishes.

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With high currents, the carbon is disintegrated to a greater distance above the point than with low.

Fig. 27 shows the form of the carbon points when the latter are burned with constant current—10 amperes. The range in P. D. was from 40 to 60 volts.

Just as the peculiar burning of the tip distinguishes a pencil fed by a low from one burned at a high current, so the form of the carbon-point differs in the case of a pencil burned with low voltage than with high. In Nos. 1, 2, 3, 4 and 5, Fig. 27, the gradual change in the formation, from a sharp projection at 40 volts to a blunt end at 60 volts is noticeable.

The "mushroom" which invariably forms in carbons burned at a low current and high voltage, is absent when the pencils are burned at high current and low voltage[1] In the former instance the thin neck of the "mushroom" often breaks thus arresting the current and extinguishing the arc. In the latter case the end of the carbon is prone to so burn away as to leave a concave outline. (See No. 1, Fig. 27.)

At 40 volts the depth of the crater measured .051 inch. At 60 volts the crater disappeared; the carbons also "flamed" at this high voltage.

With a given current there is for every brand of carbon a certain voltage, above which, if the pencil be burned, "flaming" will result. A simple trial is sufficient to determine this critical point.[2] Again there is a voltage, below which, if the carbon be burned, "hissing" takes place. With perfectly centered carbons there is no difficulty in ascertaining the latter point.

Careful observation of the arc shows that when the tension is too high for a given carbon, the walls of the crater break away, allowing the arc to play on the outside surface of the carbon. This action is always accompanied by a flame, which shoots from the negative carbon. On placing the negative pencil above and the positive below, the flame shoots down. With soft-cored carbons, well centered, one cause of flaming,—namely, liability of the arc to play laterally,—is obviated; and if the pencils be burned with the proper current and voltage, there seems to be

[1] When the carbon is impure and contains a large amount of silica, the latter is often deposited in the form of a glass bead on the point of the negative pencil. The "mushroom" alluded to in the text does not refer to this deposition.

[2] O. G. Pritchard: Electric Arc Light Carbons. London Elec. Mar. 21st and Apr. 4th, 1890.

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no reason why this disagreeable feature of the arc lamp, should not be entirely overcome.

There is not so much liability to "hiss" in a high tension system as in a low, for from the formation of the carbon-points when the pencils are burned in commercial low tension lamps, it appears that the minus carbon terminates in a small mushroom-button. The breaking of this pellicle of carbon and the consequent action of the lamp-mechanism to reduce the rise in potential due to the rupture, invariably result in the "hissing" of the arc.

Most of the irregularities in the action of arc-lamps probably result more from the unsuitableness of the carbon than from defects in the lamp-mechanism or changes in the strength of the current and P. D. in the line.

The remedy lies with the carbon-manufacturer. A careful study of the relation between the microscopical structure of the pencil and the action of the latter in a given case would be likely to bear fruitful results. Of course the field for experimentation is large, but the improvements which must necessarily follow conscientious research will undoubtedly be of great scientific as well as commercial value.

In the present state of the art of carbon-manufacture, it is the central-station manager who must exercise great discrimination in the selection of arc-light pencils for his plant. Mr. E. F. Peck has recently shown how a "comparative test of the best known carbons in the market" resulted in "a saving of 64.73 electrical horse-power in a station burning a thousand arc-lamps."[1]

But there is no reason why the carbon-manufacturer, given the condition of a lighting system as regards current, tension, required light and life of pencils, etc.—should not be able to produce a carbon specially adapted to the needs of that system.

When the root of existing defects is thus struck at, the solution of the arc-light carbon problem will be at hand.

The experiments published in this paper were made under the direction of Professor Edward L. Nichols, in the laboratory of Cornell University. The writer is indebted to Mr. A. B. Levy, R. G., for valuable assistance in the work.

[1] E. F. Peck of Brooklyn, N.Y.; Carbon Tests,—paper read before National Elec. Light Assoc'n; Kansas City Convention, Feb. 1890.

Physical Labratory of Cornell University.
Ithaca, N. Y., May 1890.

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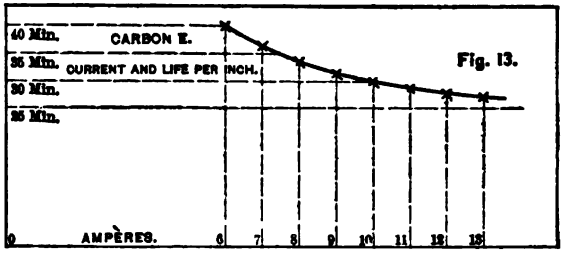


Fig. 13.

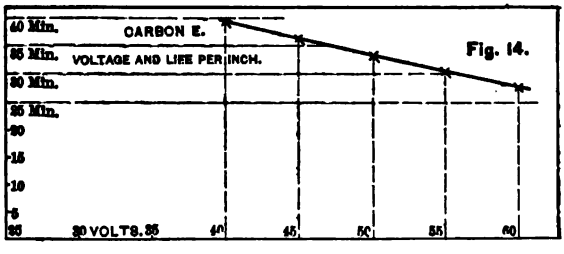


Fig. 14.

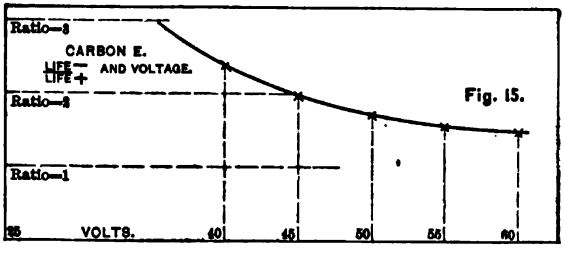


Fig. 15.

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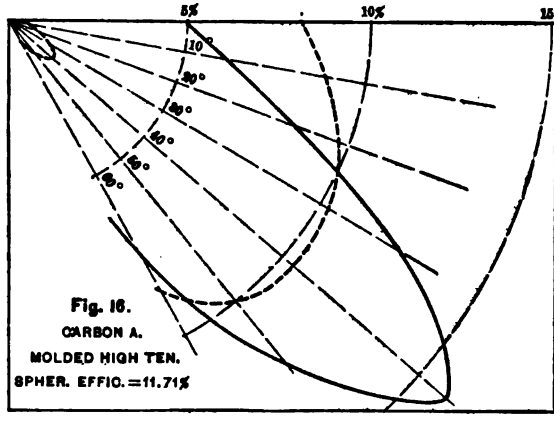


Fig. 16.
CARBON A.
MOLDED HIGH TEN.
SPHER. EFFIC. = 11.71%

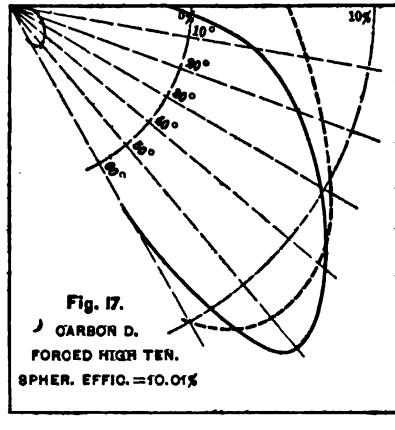


Fig. 17.
CARBON D.
FORCED HIGH TEN.
SPHER. EFFIC. = 10.01%

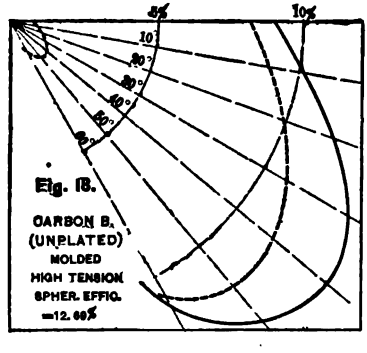


Fig. 18.
CARBON B.
(UNPLATED)
MOLDED
HIGH TENSION
SPHER. EFFIC.
= 12.66%

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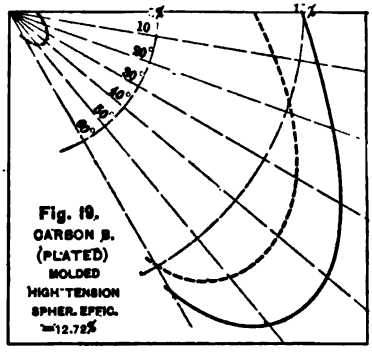


Fig. 19.
CARBON B.
(PLATED)
MOLDED
HIGH TENSION
SPHER. EFFIC.
=12.72%

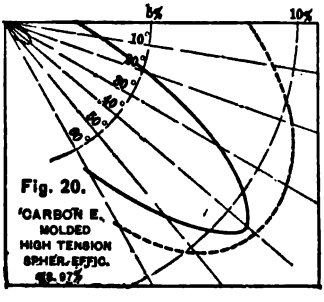


Fig. 20.
CARBON E.
MOLDED
HIGH TENSION
SPHER. EFFIC.
=8.97%

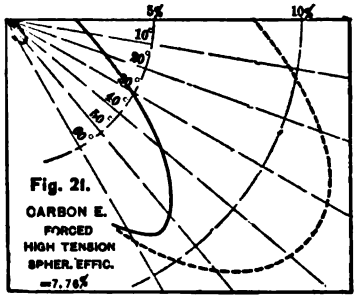


Fig. 21.
CARBON E.
FORCED
HIGH TENSION
SPHER. EFFIC.
=7.76%

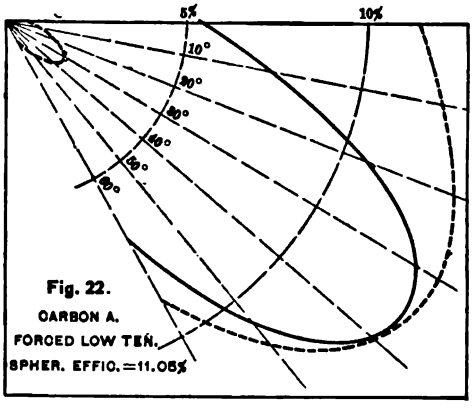


Fig. 22.
CARBON A.
FORCED LOW TEN.
SPHER. EFFIC.=11.05%

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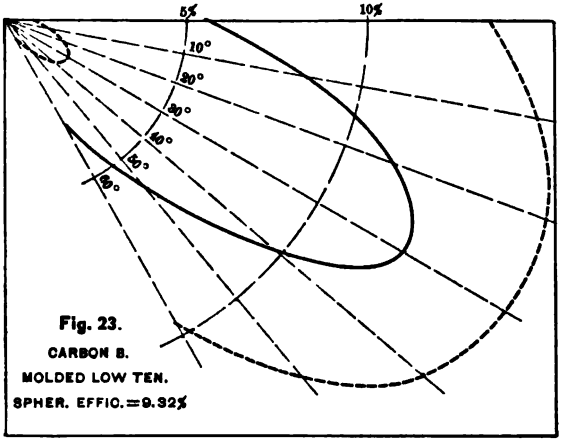


Fig. 23.
CARBON B.
MOLDED LOW TEN.
SPHER. EFFIC.=9.32%

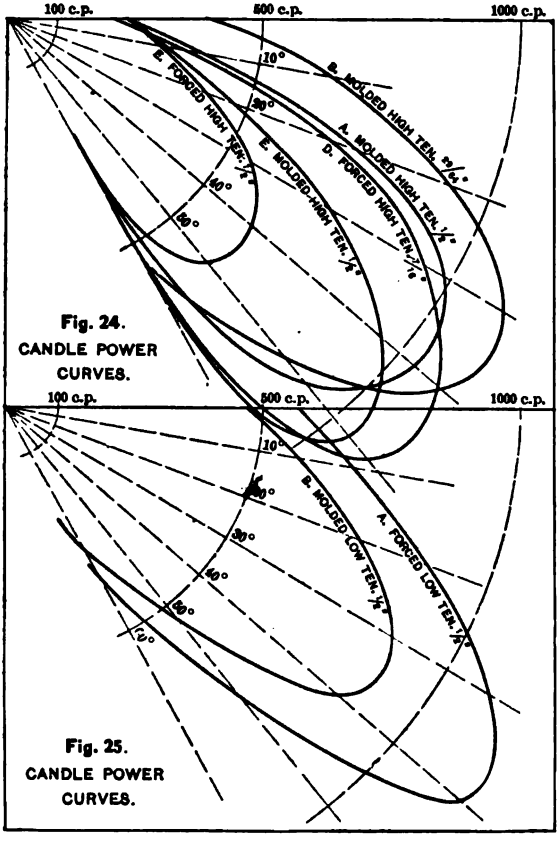


Fig. 24.
CANDLE POWER
CURVES.

Fig. 25.
CANDLE POWER
CURVES.

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*A paper read before the American Institute of Electrical Engineers, Boston, May 21, 1890.*

# PRACTICAL ASPECTS OF THE ALTERNATING CURRENT THEORY.

BY M. I. PUPIN, PH. D.

The title of this paper indicates that I propose to consider that part of the alternating current theory only which refers to machinery that has stood the test of practical experience, namely, the alternator and the transformer; the telephone is only a speeial case of these two machines.

That very eminent English physicist, Lord Rayleigh, remarked once that the introduction of alternating current machinery into commercial use would have the salutory effect of elevating the ideas of electrical engineers above the mere conceptions of volts and amperes. His prophecy has been fulfilled—sooner perhaps than he expected. The true electrical engineer of to-day is just as familiar with the exact meaning of *impedence*, *co-efficients* of *self-induction* and *mutual induction*, *difference of phase*, *static* and *viscuous hysteresis*, etc., as he was with volts and amperes at the time when that severe but well meant remark was made by Lord Rayleigh. There may be, perhaps, several old lessons which he has yet to learn; if so, he must learn them from teachers of considerably wider experience than I can pretend to possess. Not to teach the subject of our discussion, but to analyze it, is the object of this paper.

Every one of us knows the very important part which the theory of the continuous, steady current plays in the construction and running of the continuous current machinery. This theory is and always was very popular with the electrical engineer. He never looked around for a better guide in his practical work. It can be safely assumed that this popularity of the theory with practical men was chiefly due to the fact that the theory is very simple. We have here a very simple and well established funda-

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mental law, the Ohm's law namely, and most of the other relations of which this theory treats are deduced from this law by simple algebraical operations. Simplicity is the soul of truth, complicated relations are always suspected. There are many practical engineers to-day who look upon the theory of the alternating current with considerable suspicion. It seems to them to be too complicated and artificial. They also complain of a lack of sufficiently well defined distinctions between fundamental laws and arbitrary assumptions. In fact, this is the face which the alternating current theory, such as given in most of our text-books, presents to every one who is not in a position to consider the subject critically and go just a little bit beyond the badly selected limits of some of our standard text books. There is, therefore, a strong disposition on the part of some engineers to doubt the importance which others attach to the alternating current theory. If the following discussion should succeed in contributing even a small share towards the work which must be done in order to dispel these doubts, I shall be satisfied.

The features of the alternating current theory which I propose to point out with particular emphasis are the following:

First: This theory, just like the theory of the steady current, rests on a very simple and well established fundamental law of which Ohm's law is only a particular case.

Secondly: All the simple relations of which the theory treats are deducible from this fundamental relation by easy mathematical operations.

Thirdly: Problems arising in the practical running of alternating current machinery are readily solved by considering the modifications which the exact but ideal relations of the theory must undergo under conditions which we meet in practice.

Let us consider a magnetic field made up of permanent magnets, electro magnets, closed circuits with steady or variable currents flowing in them; the magnets and the conductors may be at rest or moving in any continuous manner whatever. Let us next fix two points $A$ and $B$ on one of the conductors.

Let now $E_s$ denote the electro-motive force in $AB$ due to self-induction.

Let $E_m$ denote the electro-motive force in $AB$ due to induction between $AB$, and the rest of the field.

Let $E_i$ denote an electro-motive force impressed upon $AB$ in some way or another.

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Let $D$ denote the drop of the potential between $A$ and $B$; then at any moment we have $(E_s)+(E_m)+(D)=(E_1)$.

This is the fundamental law of the alternating current theory. It is easily seen that Ohm's law is only a particular case of this fundamental relation. I have enclosed the symbols in parenthesis to denote that the absolute sign of each quantity is for the present left undetermined.

Just as the laws which govern the motions of the celestial bodies are all deducible from the single Newtonian law of gravitation, so all the laws governing the generation and the distribution of alternating current energy are deducible from that same fundamental law. The historian tell us that it took Newton twenty years to deduce his law of gravitation. It took more than one Newton to establish our fundamental law, and their labors extended over a period of more than thirty years. These Newtons of electricity were Ampère, Faraday, Lenz, Joseph Henry, F. Neumann, Helmholtz, Thomson and Maxwell.

A short critical review of the labors which led to the final formulation of the above fundamental law will not be out of place here.

Oersted's discovery was made in 1820; Ampère's and Arago's investigations of the magnetic properties of a steady electric current were brought to a close in 1823. The results of these investigations were embodied in the great work of Ampère: *Theorie des Phemomenes Electro-dynamique.* About this work immortal Maxwell speaks as follows: "The whole, theory and experiment, seems as if it had leaped full grown and full armed from the brain of the Newton of electricity. It is perfect in form, and unassailable in accuracy, and it is summed up in a formula from which all the phenomena may be deduced and which must always remain the fundamental formula of electrodynamics." The fundamental formula to which Maxwell refers is the well known differential law of Ampère. This statement Maxwell made before 1873; in 1874 Professor Helmholtz showed that it must be somewhat modified; for he pointed out for the first time that several other fundamental laws lead to the same integral law as the fundamental formula of Ampère. The integral law is the well-known law which expresses the equivalence between a simple magnetic shell and a certain steady electric current. This integral law has been verified by all experimental experience of the last seventy years. It forms the basis of the

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electro-magnetic units which we use in our electrical measurements.

The next advance was made by Faraday in 1831, eight years after the publication of Ampère's discoveries, and a gigantic advance indeed it was. If we consider Faraday's discoveries in electro-magnetic induction from the stand-point only that they supplied the electrical science of his day with additional experimental facts they would fall very short indeed of the importance which is to-day, and that too very justly, as we all know, attributed to them. It is the experimental method and the scientific reasoning by means of which Faraday arrived at his brilliant discoveries, and the view which he formed of the new phenomena that raises his work to that supreme importance to which among all the physical investigations of this century one only can aspire. I refer, of course, to those investigations which led to the final formulation of the *Principle of Conservation of Energy.*

Faraday's discoveries found immediate appreciation in the scientific world. The view, however, which he had formed about the phenomena discovered by himself, made but a feeble impression upon his contemporaries. It was too novel, and the minds of the physicists of his time were strongly polarized by the irresistible mental force of Ampère, Poisson, Green, Gauss and Weber. At that time Thomson had only just mastered his a b c, and Mawell was born in the same year in which Faraday published his first investigations on electro-magnetic induction.

The first attempt to formulate the laws which underlie all phenomena of electro-magnetic induction is contained in Lenz's discovery of the well-known rule that the direction of the currents induced in a conductor which moves in a magnetic field is always such as to oppose the motion which produces them. This discovery was made in 1834, the same year in which Faraday discovered the phenomena of self-induction. Joseph Henry's investigations on induction in general and self-induction in particular covered the period between 1832 and 1840. It is needless to say that these investigations form a necessary and a beautiful supplement to the investigations of Faraday. The resolution passed a short time ago by the American Metrological Society, to the effect to name the *unit of self-induction* after Joseph Henry is very appropriate and deserves the heartiest support of all electrical engineers. The final mathematical formulation of the law of what is to-day called *mutual induction* is due to F. Neumann,

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and is contained in his memoirs submitted to the Berlin Academy in 1845 and 1847. It was soon recognized that, since self-induction is only a special case of mutual induction, that the mathematical form of the fundamental law of self-induction must necessarily be a modification only of that of mutual induction. Maxwell, therefore, says this of Neumann: "We may regard F. Neumann, therefore, as having completed for the induction of currents the mathematical treatment which Ampère had employed for their mechanical action."

This statement of Maxwell contains more than one is apt to get from it at a glance. In Neumann just as in Ampère the mathematician predominates. They both belong to that school of mathematical physicists whose representatives are LaPlace, Poisson, Green and Gauss. Just as these great analysts had deduced most of the laws of electrostatics from the properties of a single function, the potential function, so Neumann succeeds in deducing the fundamental laws of electro-magnetic induction from the properties of a single function, the *electro-dynamic potential.* But neither were they nor was he at that time aware of that perfectly definite physical meaning which these functions enjoy to-day. This was pointed out for the first time by Helmholtz, and later on also by Sir William Thomson, the discoverers of the *Principle of Conservation of Energy* (in 1847), the fundamental principle and the infallible test-stone for all the laws of physical sciences. It is to these two men that we owe the introduction into theoretical physics of that most intelligible of all physical quantities, namely, *energy and work*, in place of mathematical symbols. With them, electrostatic potential of Poisson, Green, and Gauss, and the electro-dynamic potential of Neumann meant work; induced or any other kind of current was simply an evidence that some sort of work is being done upon the conductor. Their investigations extending from 1847 to 1853 showed clearly that the laws of electro-dynamic induction as formulated by Neumann on the basis of Lenz's discoveries was not only in full harmony with the Principle of Conservation of Energy, but that moreover this principle enables us to deduce these laws directly from the discoveries of Oersted and Ampère. This would seem to indicate that Faraday's discoveries were simply a welcome experimental confirmation of the laws which could have been deduced independently of these discoveries, and that they were therefore not essential to further progress of the

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electrical science at the time of Ampére. Maxwell, however, pointed out the real importance of Faraday's work. In 1856, only two years after he had graduated from the University of Cambridge, with the highest mathematical honors, appears his first research on Faraday's lines of force, and in 1865 already appears his great memoir, entitled: "The Dynamical Theory of the Electro-Magnetic Field." In these researches, and especially in his great treatise on Electricity and Magnetism, Faraday's discoveries, especially those on Electro-Magnetic Induction, appear to the scientific world in an entirely new light. It is on the basis of these discoveries and the view which Faraday had formed of them that Maxwell formulates the most general statement of the laws of induction. It is in the form in which the laws of electro-magnetic induction were first stated by Maxwell that they are generally known to the electrical engineers. This form not only expresses the law but also suggests the view which Farady had formed about electro-magnetic induction, which view, as we all know, has led to some of the greatest discoveries in electricity during the last 25 years.

The fundamental law which underlies the theory of the alternator and the transformer, is a convenient statement of these laws of electro-magnetic induction. The terms employed in this statement as we all know, bear a definite relation to the co-efficients of self and mutual induction, and these again depend in a perfectly well understood manner on the nature of the substances which form our magnetic field.

*The laws of electro-magnetic induction have been verified by every electrical experiment of the last forty years. They are as true as any one of the physical laws known to us, and we see therefore that since the basis of the alternating current theory is an immediate inference from the general laws of electro-magnetic induction, that this basis is as firmly established as the basis of any other department of theoretical sciences.*

*Next we have to consider some of the most important consequences which have been deduced from the above fundamental relation.* Let us take the simplest case; an alternator such as the one used by Joubert in his experiments. No iron in the armature coils, constant strength of the field magnets, constant speed of rotation. If the poles of the machines are not connected we get from our fundamental relation that the electro-motive force due to mutual induction between the magnetic field and the armature

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is equal to the impressed electro-motive force. Simple considerations lead us at once to the conclusion that the impressed electro-motive force is a sine function of the time, its maximum value that is its amplitude depending on the strength of the field magnets, the speed of rotation and the construction of the armature coils.

Let us now connect the poles by a non-self-inductive resistance such as a series of lamps. A simple mathematical operation gives us complete account of the current generated. It is, just like the impressed electro-motive force, a sine function of the time, but its phase differs from that of the impressed E. M. F. by an angle which increases with frequency and self induction, but diminishes with resistance. The relation between the current and electro-motive force is no more as simple as that given by Ohm's law. Instead of the resistance we have the *impedence.* In fact, as the reversals increase more and more the influence of the resistance upon the growth of the current becomes smaller and smaller, and in place of the effect of the resistance the effect of the co-efficient of self-induction forces itself into prominence. The *total electrical energy* produced in a unit of time is expressible in a great variety of ways. In terms of maximum impressed electro-motive force, impedance and resistance; or in terms of mean current and mean effective electro-motive force; or in terms of mean current, mean impressed electro-motive force and the cosine of the difference in phase, or again in terms of the square roots or the mean squares of the current, and of the impressed electro-motive force.

These relations between the total electrical energy produced and the other electrical quantities enable us to construct certain curves which suggest easy experimental methods of testing the truth of our deductions. These experiments were carried out by Joubert of Paris, Professor Stefan of Vienna, and Esson of England, and it was found that our theoretical inferences were completely verified. For full references consult Sylvanus Thomson: "Dynamo Electric Machinery," and a very excellent work of Professor Kittler, "Handbuch der Electro-Technik, Vol. II., Part 1."

This perfect agreement between theory and experiment will surprise no one who is acquainted with the working of Hughes induction balance, with experimental methods of determining the co-efficients of self and mutual induction, and with the beautiful

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induction experiments of our learned ex-President, Professor Elihu Thomson. All these beautiful experimental designs are also inferences from our fundamental relation, inferences considerably more ingenious but also considerably less direct than the inferences which we have considered in the simple case just discussed.

We next consider the energy which is available in the external circuit. This is the part of the energy which is for sale, and it is well to inquire what means we have in determining the cost of production under conditions as simple as the above. If the conductors through which we send our current to the consumers have no self-induction, as is generally the case, the task is extremely easy. Simple analytical deductions from our fundamental law suggest the watt-meter, the electrometer, and a variety of other instruments whose indications depend either on the heating or on the magnetizing effect of the alternating current. With reference to this point we can consult several very excellent works like Grey's Electric Measurements, Ayrton and Perry's Practical Electricity and Kittler's Book.

Our methods of measurement in this simple case are exact deductions from an exact fundamental law and can be made in practice as exact as we choose to make them.

With reference to the watt-meter it is well to observe that under certain conditions, not at all difficult to realize in practice, it can measure the output of a machine even if the current does not follow the simple sine law. With regard to this point I refer you to investigations of Professor Stefen of Vienna, published in the reports of the Vienna Electrical Exhibition in 1883.

Let us now make the next important step in our discussion. We'll consider now the transformer under the following simple conditions: There are no Foucault currents nor hysteresis in the core of the transformer and the relation between the strength of the primary current and the mass of the iron core is such that the magnetization of the latter never approaches the saturation point. It seems desirable to work out this case analytically and at somewhat greater length.

Let $L$ be the co-efficient of self-induction of the primary coil.
" $N$ " " " " " secondary "
" $M$ " " mutual induction.
" $R$ " resistance of the primary coil.
" $S$ " " " " secondary coil (both external and internal.)

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Let $x$ " current of the primary coil } at any moment.
" $y$ " " " secondary " (

Our fundamental relation

$$(E_s)+(E_m)+(D)=(E_l)$$

will now be

$$L\frac{dx}{dt}+M\frac{dy}{dt}+Rx=E_0 \sin 2\pi zt \text{ for the primary coil.}$$

$$N\frac{dy}{dt}+M\frac{dx}{dt}+Sy=o \qquad \text{" secondary "}$$

$E_0$ is the amplitude of the electromotive force impressed by the alternator upon the poles of the primary coil of the transformer.

Our object is to express $x$ and $y$ in terms of the known quantities $L, M, N, R, S$ and $t$. We proceed in exactly the same way as in the solution of simultaneous equations in Algebra We simply eliminate one of the unknown quantities, either $x$ or $y$, and obtain a single equation containing only the other unknown quantity. Seeing that we have not a sufficient number of equations to do that we differentiate again and obtain two more equations, viz:—

$$L\frac{d^2x}{dt^2}+M\frac{d^2y}{dt^2}+R\frac{dx}{dt}=-2\pi z\,E_0\cos 2\pi zt.$$

$$N\frac{d^2y}{dt^2}+M\frac{d^2x}{dt^2}+S\frac{dy}{dt}=o.$$

From these four equations we eliminate $x$ and its differential coefficients and obtain, putting $2\pi z=p$.

$$(LN-M^2)\frac{d^2y}{dt^2}+(LS+NR)\frac{dy}{dt}+RSy=-pE_0M\cos pt. \quad (1)$$

This relation between the current in the secondary coil and the other quantities must subsist at every moment, and therefore also when $t=o$. We have then

$$(LN-M^2)\left[\frac{d^2y}{dt^2}\right]_0+(LS+NR)\left[\frac{dy}{dt}\right]_0+RS(y)_0 = -pE_0M \quad (2)$$

The suffix zero along the parenthesis denotes that the value of the quantity enclosed in the parenthesis is to be taken at the time zero.

To one dealing with abstract mathematical symbols equation (1) would present considerably serious difficulties of working out the details of his solution. But to you who are dealing with physical things, and to whom every symbol in equation (1) pre-

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sents something that you have handled for years and years, you can put down the solution of (2) at once. Here it is

$$y = A_2 \sin 2\pi (zt - \varphi_2). \qquad (3)$$

The only thing that is unknown in this equation yet is the constant $A_2$. It is evident that it is some function of the constants $L$, $M$, $N$, $R$, $S$, $E_0$, $p$ and $t$. We can determine it from equation (2) as we shall presently see. There is one point which I wish to emphasize particularly at this stage of our discussion, and that is the marked difference between abstract mathematical operations and those mathematical operations which are employed in the discussion of physical problems. The abstract mathematician is necessarily more or less indifferent to the physical meaning of his symbols; the mathemathical physicist is more fortunate. The physical meaning of his mathematical symbols makes his mathematical operations comparatively easy. Let our example illustrate this feature of mathematical physics.

Consider two telephones; one acting as a receiver and the other as a transmitter. We can construct and connect them in such a way, that they will resemble in every particular our example, namely the transformer in series with the alternator. In the case of these telephones the impressed electromotive force is a harmonic function of the time, the same harmonic function which describes the motion of the diaphragm plate of the transmitter. Now since in the receiving telephone we hear the same sound which is acting upon the diaphragm of the transmitter we conclude that the induced current which causes the vibrations of the diaphragm of the receiver is the same harmonic function as the impressed E. M. F. This induced current corresponds to our current $y$. Therefore, the secondary current of the transformer is the same function of time as the impressed E. M. F. This consideration enables us to put equation (2) down without going through all the mathematical steps which the pure mathematician would have been obliged to make before arriving at that equation.

(NOTE:—If the E. M. F. which the alternator supplies to the transformer had been of the form

$$\Sigma' A_n \sin 2\pi znt + \Sigma' B_n \cos 2\pi znt.$$

the induced current would evidently be of the form

$$y = \Sigma' a_n \sin 2\pi (nzt - \varphi) + \Sigma' C_n \cos 2\pi (nzt - \varphi)$$

where $\Sigma' a_n \sin 2\pi znt$ stands for

$a_1 \sin 2\pi zt + a_2 \sin 4\pi zt + a_3 \sin 6\pi zt + \cdots + a_n \sin {}^2\pi nzt$

and $a_1, a_2, \cdots a_n$ are constants to be determined in the same

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way as we are presently going to determine our constant $A_2$. The same remark applies to the other summation symbols.)

The determination of the constants $A_2$ and $\varphi_2$ is a simple algebraical operation. From (3) we have

$$(y)_0 = -A_2 \sin 2\pi\varphi_2 \qquad \left[y\right]_{t=\frac{T}{4}} = A_2 \cos 2\pi\varphi_2$$

$$\left[\frac{dy}{dt}\right]_0 = p\,A_2 \cos 2\pi\varphi_2 \qquad \left[\frac{dy}{dt}\right]_{t=\frac{T}{4}} = p\,A_2 \sin 2\pi\varphi_2$$

$$\left[\frac{d^2y}{dt^2}\right]_0 = p^2 A_2 \sin 2\pi\varphi_2 \qquad \left[\frac{d^2y}{dt^2}\right]_{t=\frac{T}{4}} = -A_2 \cos 2\pi\varphi_2\, p^2$$

and therefore

$$A_2\{[p(LN-M)-RS]\sin 2\pi\varphi_2 + p(LS+NR)\cos 2\pi\varphi_2\} = pME_0$$

or $A_2\{a \sin 2\pi\varphi_2 + b \cos 2\pi\varphi_2\} = pME_0$ from $(2_a)$

$A_2(a \cos 2\pi\varphi_2 - b \sin 2\pi\varphi_2) = o$ " $(2_b)$

The second of the last two equations gives $\tan 2\pi\varphi_2 = \frac{a}{b} = \frac{p^2(LN-M^2)-RS}{p(LS+RN)}$ From the first we get, considering that

$$\sin \pi\varphi_2 = \frac{a}{\sqrt{a^2+b^2}}, \quad \cos 2\pi\varphi_2 = \frac{b}{\sqrt{a^2+b^2}},$$

$$A_2 = \frac{pME}{\sqrt{a^2+b^2}}.$$

$$a^2+b^2 = p^4(L^2N^2 - 2M^2LN + M^4) + 2p^2RSM^2 + R^2S^2 + p^2(L^2S^2 + R^2N^2)$$
$$p^2L^2(S^2+p^2N^2) - 2p^4M^2LN + p^4M^4 + R^2(S^2+p^2N^2) + 2p^2RSM)$$
$$= p^2\left[\frac{L-p^2M^2N}{S^2+p^2N^2}\right]^2(S^2+p^2N^4) + \left[\frac{R+p^2M^2S^2}{S^2+p^2N^2}\right]_2$$
$$(S^2+p^2N^2)$$
$$(S^2+p^2N^2)(R_1^2+p^2L_1^2)$$

Hence:

$$A_2 = \frac{pME}{\sqrt{S^2+p^2N^2}\sqrt{R_1^2+p^2L_1^2}}$$

Proceeding in exactly the same way, we get for the current in the primary winding:

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$$x = \frac{E_0}{\sqrt{R_1^2 + p^2 L_1^2}} \sin 2\pi (zt - \varphi_1)$$

$$\text{Where } \tan 2\pi \varphi_1 = \frac{p L_1}{R_1}$$

This gives us a complete analytical solution of the ideal transformer. We can assume with perfect safety that the number of electrical engineers is very small indeed who will consider the analytical process through which we have just gone through as very difficult, and yet it is one of the most difficult mathematical processes which we meet in that part of the alternating current theory which I proposed to discuss, and which at the present time is of immediate interest to all practical engineers. You may, perhaps, ask: But what has this mathematical analysis to do with the practical aspects of the alternating current theory? Simply this: it bears upon the question whether the alternating current theory is or is not entirely within the reach of most of the electrical engineers, and this question is of eminently practical importance.

I considered the mathematical problem of the ideal transformer for the purpose of showing that its consideration does not involve any difficult mathematical operations, and not for the purpose of establishing and discussing the well-known relations between the various quantities which we just obtained. Any further consideration of the problem seems therefore superfluous.

The question of the efficiency and self-regulation in the case of a transformer of this kind is, as we all know, a very simple one, and can be answered at once from the above relations.

The *third point* which I proposed to consider was this: *What are the modifications which must be introduced into the relations so far obtained in order that our calculations should cover also conditions under which the alternator and the transformer are worked in practice.*

In order to get these practical conditions we have to drop one by one, several of the suppositions on which our calculations so far have been based. The first of the suppositions was that the effective magnetic field of our alternator was a simple harmonic one; the second suppositon was that the armature coils contained no iron. The immediate consequence of the removal of these two suppositions will be that the impressed electro-motive force of the alternator will no longer be a simple sine function but a more complicated harmonic function of the time. The same is

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true of the current, and it is evident from the remark made above in connection with the analytical consideration of the ideal transformer that the current will be expressible by a harmonic function of the same form as that for the impressed electro-motive force. Since the coefficients of induction are now much larger on account of the presence of iron in the armature coils the differences in phase between impressed electro-motive force and the current will be larger than without iron in the armature. Dropping now our third supposition that the magnetic permeability of iron is a constant quantity we infer that since for higher magnetizations this coefficient becomes smaller, that the differences in phase will be smaller than calculated for constant permeability. Dropping finally our last hypothesis, namely, that there are no Foucault currents or hysteresis we introduce a further modification into the values of our coefficient of induction and consequently also into the differences of phase. The same remarks apply to the transformer also. In what direction these modifications will effect the efficiency of our machinery is a question familiar to all of us. A complete general mathematical treatment of the alternator and the transformer is in the present condition of our knowledge of the magnetic properties of iron an impossibility; but fortunately for us such a treatment would also be more or less superfluous for practical purposes. Thanks to the profound investigations of Rowland, Hopkinson, Ewing, Wasburg, Bidwell, and others, we know just enough of the magnetic properties of iron to enable us to obtain a very approximate solution of the most general form of our problem. On this point we can consult the well known excellent investigations of Blakesley and Fleming and especially of Hopkinson, Kapp and Ferraris. The graphical methods of Blakesley and Kapp are very valuable. This solution of the general problem has been tested experimentally by Ferraris, Hopkinson, Ayrton and Perry and others and found to give a satisfactory account of the phenomena which actually take place in the practical working of the transformer. The very valuable experimental investigations of two member of this Institute, Dr. L Duncan of Johns Hopkins University, and Mr. Ryan of Cornell, we all know and appreciate; they afford us an excellent illustration of a fact which deserves a serious consideration on the part of every true electrical engineer, and that fact is that electricians whose methods of investigation show a perfect mastery of the theory can design and carry out experiments of

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eminently practical nature. The secret of it is that there is actually no real difference between the theoretical and the practical side of electricity.

As to the question of insulation of wires carrying high tension alternating currents, well, we know Sir W. Thomson's opinion on this point.

All these considerations which I could only point out here, but whose complete discussion can be easily gathered from the current electrical literature, seems to me to justify the following conclusion: *The generation and distribution of alternating current energy is based on as simple a theory as any other form of energy. The agreement between theory and practical experience is so perfect that the two form necessary supplements to each other. No difficulty was ever met in practice which the theory did not point out, and no difficulty which the theory can point out is beyond the reach of skilled practical engineers. There is therefore not the slightest ground on which objection could be be raised against the commercial use of this form of energy.*

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THE PRESIDENT:—If there is no further discussion of this, we will pass to the next paper: "Magnetic Data of the Sprague Street Car Motor," by H. F. Parshall, of New York City, to be read by Mr. Crosby.

(Mr. Crosby read the paper.)

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*A paper read before the General Meeting of the American Institute of Electrical Engineers, Boston, Mass., May 21st, 1890.*

# MAGNETIC DATA OF THE SPRAGUE STREET CAR MOTOR.

BY H. F. PARSHALL.

Figures giving the ratios of the lines of force through various parts of the magnetic circuit to the lines of force through the armature have occasionally been fully published, the most noticeable being those given in a paper by Hopkinson some years ago. These ratios vary in the same type of dynamo or motor with any change of proportion; or, to put it in another way, in order that these ratios may remain constant in the same type, the ratios of the magnetizing force in the one part of the magnetic circuit to the magnetizing force in the other parts must also remain constant.

In making calculations on various motors made by the Sprague Company, I have found it necessary to confirm the assumed values of these ratios by measurements. It is the object of this paper to give the results of the measurements made on the street car motor, together with sufficient description, to make the values found of some use to those engaged in similar work. If I had had any intention of publishing these results, I would have endeavored to make them, in some ways, more complete than they now are, but so little detailed information exists on this subject, I have decided to give the result of my work up to date on this particular motor. The conditions under which this work has been carried on have not at all times been the most favorable for accuracy, but in the main, the results have been satisfactory.

Plate 1 shows the various peculiarities of the magnetic circuit, and gives dimensions of the several parts. The most noticeable points are:

The bell mouthing of the pole pieces shown in the section "A

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B A." This bell mouthing greatly lessens the sparking, as does also cutting away of the tips of the pole pieces, as shown in "A B." With these modifications the brushes can be shifted an angle of 20 degrees without serious sparking.

The other noticeable points are the cast-iron side brackets, the width of the yoke and its comparative thinness.

The method of getting the ratio of the lines of force in one part to the lines of force in another was the usual one. Coils of a few turns were wound around these parts, and connected to a ballistic galvanometer, and when the needle was standing at zero, a known magnetizing force was suddenly reversed.

The galvanometer used was an Edelmann with a heavy ring form of needle very slightly damped. The deflections being small, it was assumed that the first throw was proportional to the induction through the measuring coil. The magnetizing coils were those commonly used on this motor.

Each coil was wound approximately to a depth of 4 centimeters, and along the cores 8.5 centimeters.

Coils were as follows:

FIRST. Nearest the pole piece 28 turns per layer, 11 layers.

SECOND. 31 turns per layer, 11 layers.

THIRD. 31 turns per layer, 13 layers.

This gives 2104 turns for both cores, or with a current of 6.75 ampéres, which was used throughout a magnetizing force of 14200 ampére turns.

By noticing the curves in Fig. 2 it will be seen that this is the part of characteristic upon which the motor is most frequently worked. With different values of magnetizing force, different values of the ratios would be found. This becomes evident when we remember that the resistance of the gap remains constant, while the resistance of the iron increases with the magnetizing force. For this reason the curves of magnetization of the *different* parts of the magnetic circuit are not given.

The measuring coils were 4 turns of wire wound around the armature core at E. F., on the pole piece; at A. B., on the magnet core, midway between the ends and on the yoke at G. H., had it been possible a coil would have been wound around both the yoke and side brackets.

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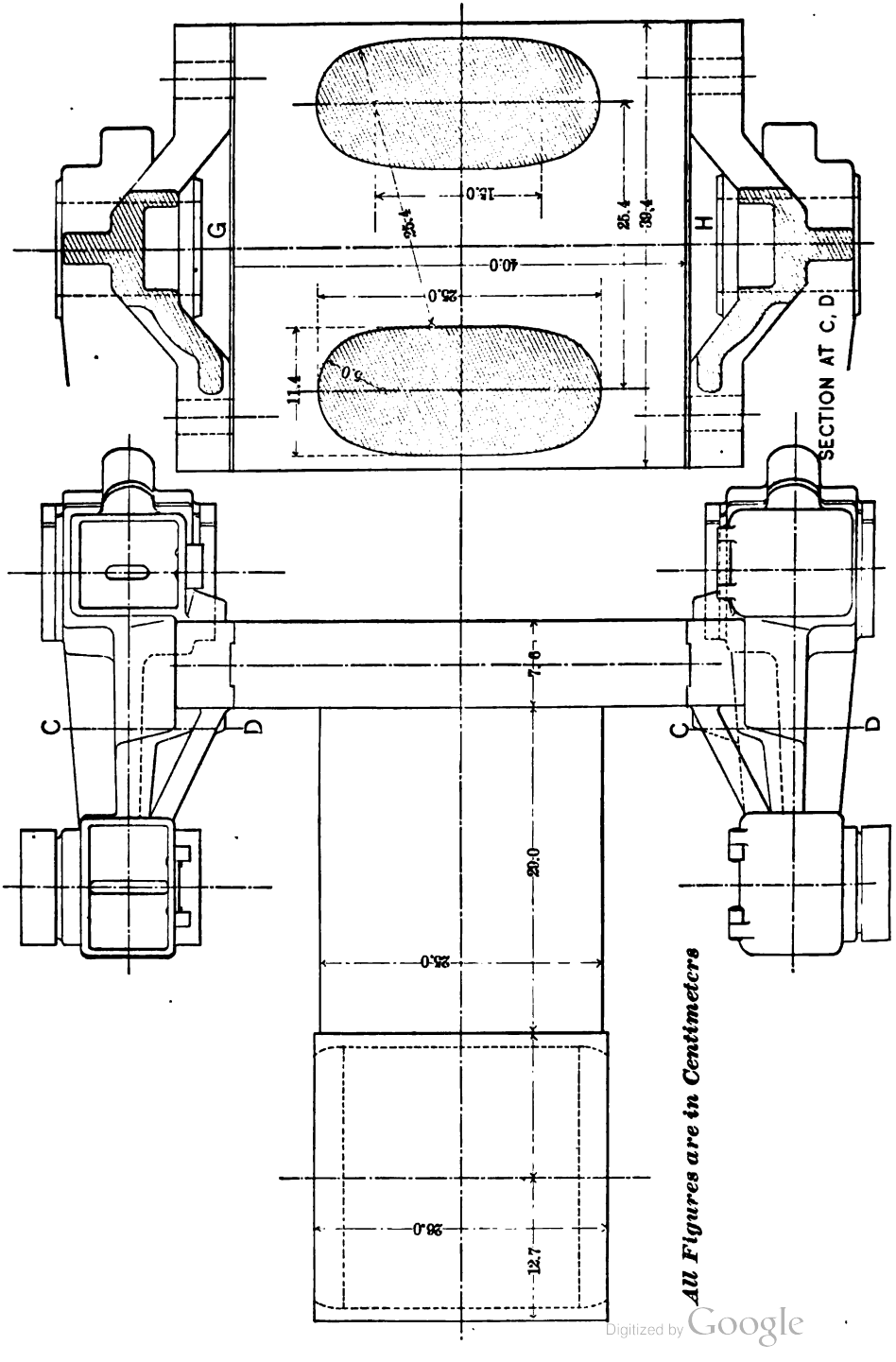


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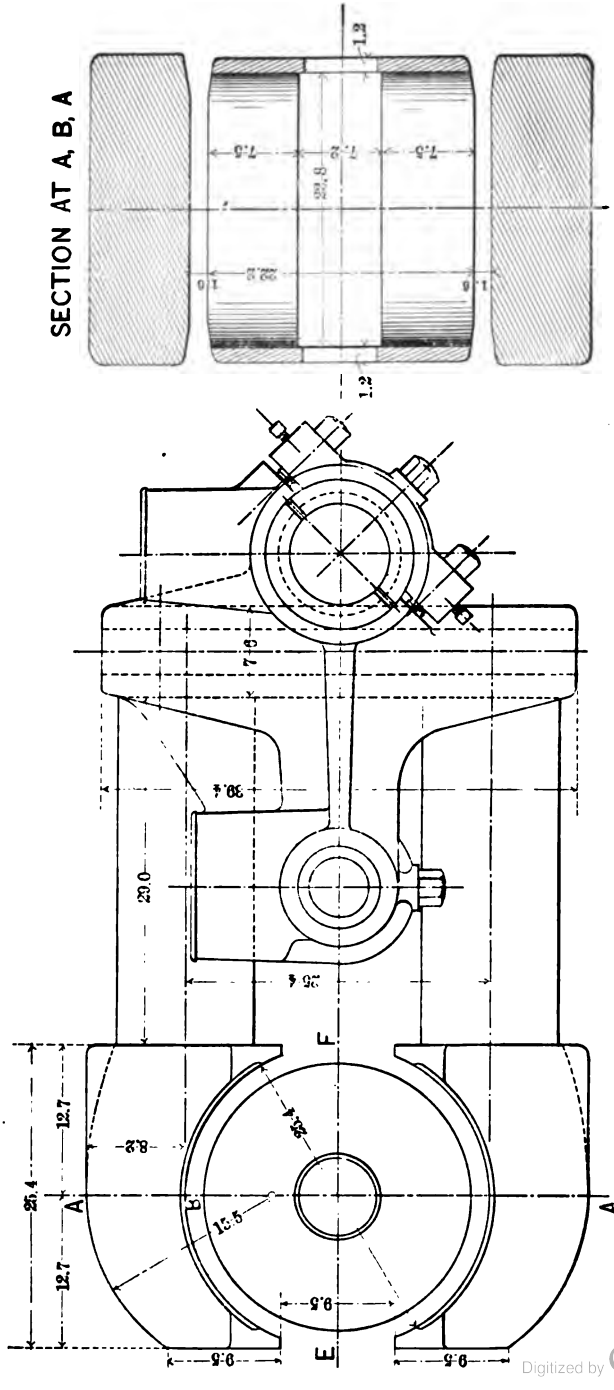


FIG. 1.—SPRAGUE STREET CAR MOTOR.

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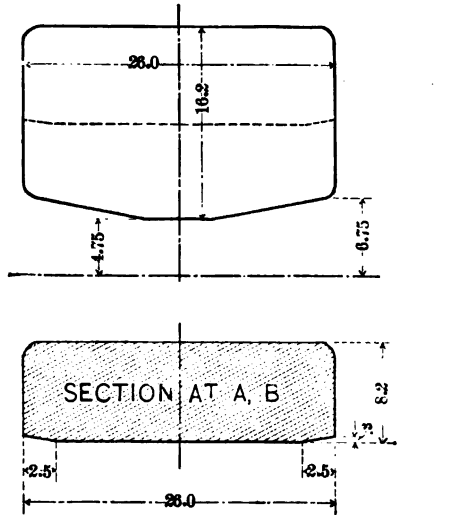


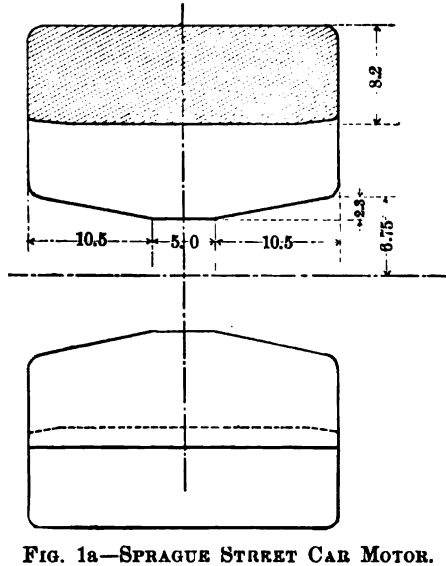


FIG. 1a—SPRAGUE STREET CAR MOTOR.

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The following values were found:

$$\left.\begin{array}{l}\text{Lines through magnet}\\ \hline \text{Lines through armature}\end{array}\right\} \quad 1.45$$

$$\left.\begin{array}{l}\text{Lines through middle of yoke}\\ \hline \text{Lines through armature}\end{array}\right\} \quad 1.27$$

$$\left.\begin{array}{l}\text{Lines through middle pole piece}\\ \hline \text{Lines through armature}\end{array}\right\} \quad 0\ 666$$

Cast iron pole pieces.

$$\left.\begin{array}{l}\text{Lines through magnet}\\ \hline \text{Lines through armature}\end{array}\right\} \quad 1.52$$

$$\left.\begin{array}{l}\text{Lines through middle of yoke}\\ \hline \text{Lines through armature}\end{array}\right\} \quad 1.33$$

$$\left.\begin{array}{l}\text{Lines through middle pole pieces}\\ \hline \text{Lines through armature}\end{array}\right\} \quad 0.7$$

The effect of the leakage from the side brackets is shown in Fig. 2, the upper curve being the characteristic with them removed, and the lower curve being the characteristic with brackets on. The dropping of the curve shows the magnet cores are sooner saturated with the brackets on. The difference is small. It would be somewhat greater did not the brackets reinforce the yoke. These curves were first obtained by separately exciting the fields, and taking the number of revolutions, with a driving current of one ampére through the armature.

The lower curve has, by comparison, been found to be a close approximation to the characteristic when the armature is run with currents for which it was designed.

Fig. 3 shows the characteristics of two motors, one with the wrought-iron pole piece, and the other with the cast-iron pole piece, the gap being 2.85 instead of 3.2, the side brackets being on in each case. The difference between these two characteristics is somewhat striking, and carries its own lesson.

I wish here to acknowledge my indebtedness to Mr. G. J. Scott for the assistance he has given me in making measurements.

The plate shows two forms of pole piece; one has a full line. This is the cast iron; the dotted line shows the wrought iron pole piece.

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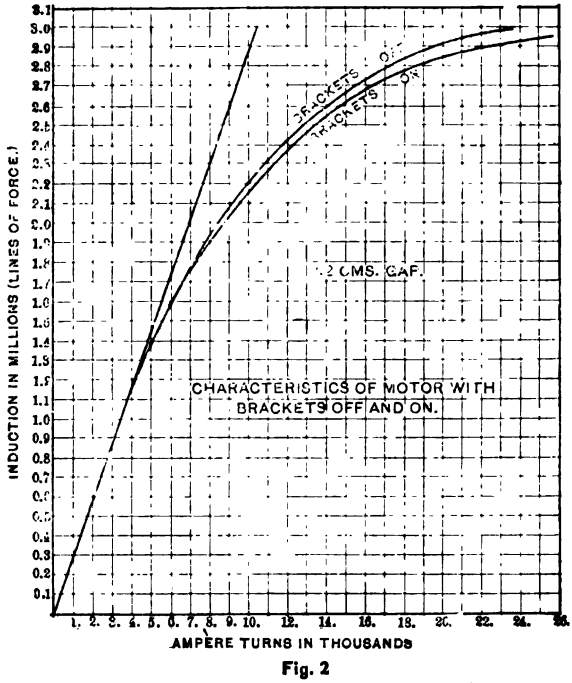
INDUCTION IN MILLIONS (LINES OF FORCE.)
AMPERE TURNS IN THOUSANDS
BRACKETS OFF
BRACKETS ON
2 CMS. GAP.
CHARACTERISTICS OF MOTOR WITH BRACKETS OFF AND ON.

Fig. 2

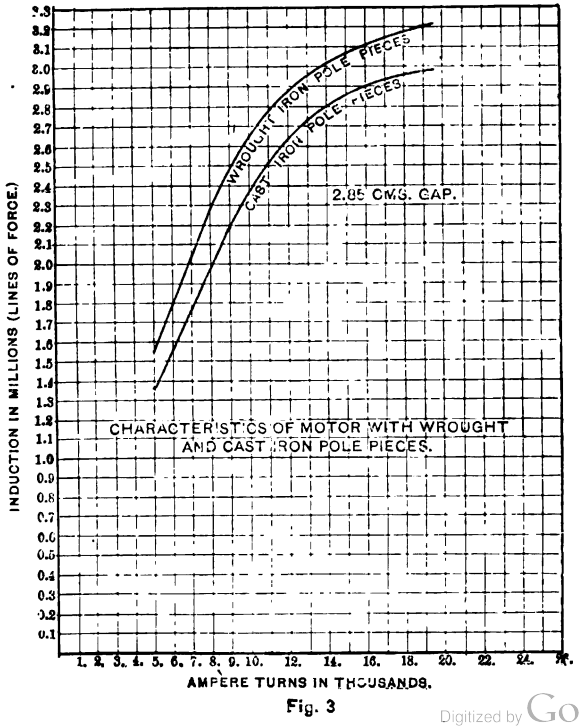
INDUCTION IN MILLIONS (LINES OF FORCE.)
AMPERE TURNS IN THOUSANDS.
WROUGHT IRON POLE PIECES.
CAST IRON POLE PIECES.
2.85 CMS. GAP.
CHARACTERISTICS OF MOTOR WITH WROUGHT AND CAST IRON POLE PIECES.

Fig. 3

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DISCUSSION.

DR. LOUIS BELL: It may be of some interest to know of the results to be obtained from the old type of Sprague motor. I had occasion recently to make tests on the old type of motor, and in that case the ratio between the number of lines passing through the armature and those in the field magnet was 1.65, but I found it was not a fixed quantity; that is, in motors taken apart and put together for the purpose of repairs. I doubt very much that they would be anywhere near constant for a year's service.

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*A paper read before the General Meeting of the American Institute of Electrical Engineers, Boston, Mass., May 21st, 1890.*

# THE INDUSTRIAL UTILIZATION OF THE COUNTER-ELECTROMOTIVE FORCE OF SELF INDUCTION.

BY THOMAS D. LOCKWOOD.

It may as well be confessed at the outset that although my production has cost me considerable thought, it does not claim to advance any original ideas. Its claims to attention are based solely upon its merits as a chronicle. There seems to be among the modern race of electricians not a few who regard that species of counter-electromotive force which is the subject of this paper, as being the only species in the genus. While of course this view is erroneous, it is easily accounted for by the notorious fact that the American Electrician as a class has little time to study. The fact, however, while it is indeed as I have termed it, "notorious," is still to be deplored; for it is certain that were electricians fully informed not only of the researches which took place before their own, together with the results of the said researches, whether these results took the form of success or failure, there would be much less valuable time wasted in supposed original research; there would be far fewer valueless inventions produced; and there would be a much smaller amount of subsequent vexations and useless litigation.

While counter-electromotive force, generally speaking, is a genus; the counter-electromotive force of self-induction is a species, and while an illustration of this statement will no doubt to most of us be an operation something in the nature of carrying coals to Newcastle, or water to the Mississippi valley, I cannot believe that it will be a waste of time, since doubtless we have many members who have not fully considered the subject.

Consider for a moment a definition of electromotive force.

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What shall we say it is? It certainly is not a natural force like gravitation, and I do not think we can do better than concede that we call it a force, simply because it is convenient so to do; and define it as any agency tending to set up that form of motion or vibration which we call electricity; or if you please, any agency tending to the manifestation of electricity.

We are constantly hearing that a current of electricity is the result of a difference of potential between two points connected by a conductor, but though this statement through constant repetition has come to be as it were "human nature's daily food;" I am inclined to consider it as being after all but a mathematical way of saying that a current of electricity is the necessary result of an electromotive force provided with a closed conducting circuit. For it is the electromotive force which first determines the difference of potential, which therefore may be considered as being a kind of initial result. Following out this train of thought, it appears then that electromotive force is a function of the source or instrumentality which develops the current, and expresses the totality of difference of potential in the entire circuit; and while we may properly speak of the difference of potential, or fall of potential between any two points on the circuit, I think we can not with equal propriety speak of the E. M. F., in any other way than as something pertaining to the source.

And further consideration of the same idea, shows the incorrectness of the popular phrase often used of late years even by many eminent and able electricians, "a *current* of so many *volts*," the electromotive force being in no sense, near or remote, an attribute of the current.

To run counter to anything, is to run against it, to run in opposition to; to act opposedly; and so a "counter electromotive force" may be defined as any agency tending to develop a current of electricity in a circuit, opposite in direction to that of the current excited therein by the initial electromotive force.

A familiar instance is that of connecting up in an electric circuit a certain number of cells in opposition to a number of other cells. This constitutes a primary counter-electromotive force and its inclusion in the circuit reduces the current in two ways; first by reducing the acting electromotive force to a value equal only to the algebraic sum of two opposing forces; and secondly by adding internal resistance of the value of the cells added in opposition.

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Another familiar illustration is found in that ingenious class of dynamo regulator, which acts by causing the opposing brushes to creep around the commutator and according to the work which is being done in the external circuit, to include in the circuit (by increasing or decreasing the lead of the brushes,) a greater or less number of armature coil sections exerting an electromotive force in opposition to the electromotive force which is developing the working current.

In these cases a utilization is made of counter-electromotive forces deliberately organized for the purpose, but they are not counter-electromotive forces due to self-induction.

At a very early period in the history of voltaic electricity it was discovered that there was some deteriorating force at work in every voltaic battery which depreciated the current to a much greater extent than exhaustion of the liquids or consumption of the solid elements could account for; and in 1801, Gautherot found[1] in this phenomenon which has foolishly been called "polarization," the germ of the secondary cell. He discovered that wires of platinum or of silver which had been used to decompose salt water acquired a power of themselves yielding a current when placed in acidulated water and could cause muscular contractions of a frog's leg and produce the galvanic test. And subsequently it was ascertained that the operation of a voltaic battery tended to coat the negative plate with hydrogen which tended to set up a counter-electromotive force between the hydrogen and the surface of said plate, which thus reduced the available energy of the battery, and that this action could be transferred to the electrodes of the same battery, if placed in a separate decomposing cell, and there tended to form electrically opposed surfaces which could themselves be used to develop a current in a direction opposite to that of the original current. As we all know, this operation long regarded only as an unmitigated evil, is now utilized in the formation and operation of cells adapted for the electrical storage of energy.

The counter-electromotive force of self-induction distinct from the foregoing, is that discovered by Professor Henry; and its most important use is that which has been mainly brought out in association with the employment of alternating or other currents for the purpose of regulation By reason of the fact that

1, See Izarn's Manual du Galvanisme, Paris, 1804, and Phil. Mag., 1806, Vol., XXIV. p. 185.

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*this* utilization has proved to be overwhelmingly important, the electrical fraternity has partially lost sight of many earlier and contemporary instances of the useful employment of self-inductive electromotive force; which is indeed a close analogue in its character, mode of generation, and capabilities of use in regulation to that developed and utilized in the operation of electromotors.

Firstly—I desire to point out that though Henry was the first to study and discuss self-induction, he was not the first to notice its effects.

Until quite recently I, together with nearly everyone else, had supposed that the earliest published notice of this phenomenon was Henry's account [2] of his observation, published in 1832; but I have in my researches on the subject, dug out the fact that this is not so. I find that an experimentalist, Vassali-Eandi by name, records that [3] with a pole of fifty pairs he found that the fluid passed along a copper wire plated with silver, 1,151 feet in length, in a time incommensurable; the shock in this case was three times as strong as that experienced by immediately touching the two extremities of the pile.

The above isolated statement of facts stands I believe alone, and there is no record that it led to further research.

Henry on the contrary perseveringly pursued, and made himself master of the subject; and the record of his original observation, brief though it is, details the appearance of a vivid spark on the breaking of a battery circuit, if a wire thirty or forty feet in length be included in that circuit; shows that the effect is increased by coiling the insulated wire into a helix; and that the effect depends in some measure on the length and thickness of the wire. The note concludes with these remarkable words "I can account for these phenomena only by supposing the long wire to become charged with electricity which by its reaction on itself projects a spark when the connection is broken."

This, though brief, is then the first analytical notice of the electromotive force of self-induction, so long erroneously denominated after its result, the "extra current."

It is unfortunate that Prof. Henry did not for some time pursue the subject, and we do not hear from him again until March, 1835.

2. Silliman's American Journal of Science, July, 1832, Vol. XXII. pp. 403-8.
3. Philosophical Magazine, Vol. XV. 1803; also Phil. Magazine, Vol. 3, 4th ser. 1852, p. 455.

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Meanwhile his great contemporary, Faraday, had taken it up pursuant to an observation of one William Jenkin, and showed self-induction to be a corollary of his former masterly experimental researches in magneto-electro induction.

Faraday notes [4] the following points: "Self-induction exists in simply helices as well as in electro-magnets, though not to the same degree.

Helices are superior in developing induction to straight wires, and long wires to short ones.

Self-induction practically disappears when the conductor is permitted to inductively act upon a neighboring closed circuit.

That the amount of self-induction depends on the length of wire exposed to inductive action.

An iron core within helices, much exalts the action of self-induction.

The self-inductive effect depends not "upon a permanent state of the core, but on a change of state."

Henry now again takes the matter and in a consecutive series of papers, practically runs it to earth.

[5]In a paper of March, 1835, he gives more in detail some of the conditions of the development of self-induction. A long wire is better than a short one; a helix better than a straight wire of equal length. He also describes a shocking coil, and also a deflagration coil of but one wire in which self induction is involved.

[6]A little later he elucidates the origin and properties of self-induction and records that some additional energy appeared when iron was used as a core, but not much, because his coils were flat and not elongated helices. He ascribes all of these effects to dynamical induction, and shows that in a coil of a number of convolutions the convolutions act inductively on each other, and inferentially that the energy of the self-induction is the sum of that of the different coils.

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4. Experimental Researches in Electricity, Faraday, 1839, Vol. Ninth series, p. p. 332-343, read before the Royal Society, Jan'y 29, 1835. A series of notes "The Influence by Induction of an electric current on itself."

5. Journal of the Franklin Institute, March, 1835, Vol., XV. pp. 169–170, Sillimans American Journal of Science, July, 1836, Vol., XXVIII, pp. 327 and 331 and Scientific Writings of J. Henry, Washington, Vol. 1, pp. 87-91.

6. Transactions American Phil. Soc., N. S., Vol. V, pp. 223-231, reprinted in Sci. Writings, J. Henry, Washington. 1886, Vol., 1, pp. 92–100.

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[7]In a third paper further experiments in self-induction or with the extra current, as it was then called, are discussed. We learn that the electromotive force of any self-induction coil within certain limits is dependent upon the length of the coil.

That the form of the coil has considerable influence on the intensity of the action. In the experiments of Dr. Faraday, a long cyl ndrical coil of thick copper wire inclosing a rod of soft iron was used.

This form produces the greatest effect when magnetic reaction is employed.

The "extra current" of self-induction developed in a coil, is controllable by the presence of an immediately adjacent independent coil. It is energetic when the circuit of the adjacent coil is open but absent when the adjacent circuit is closed."

Of course it is impossible in this paper even to indicate the many good things which are spread before the reader of the researches of both Faraday and Henry. They are well worth study, and in fact they laid a solid foundation for the work which is being done now.

Both discovery and invention are displayed in their work, much of which has only found its sphere of action within the last four years; for it is emphatically true as has been said by Mr. W. H. Preece, "that though we are accustomed to hear that necessity is the mother of invention, the child is as a matter of fact often born before its parent.

As is frequently the case with electrical discovery, self-induction was for long recognized, that is for the most part, and by the generality of electricians only as an unwelcome guest whose parting was to be speeded.

It was manifested mainly by an undesirable spark appearing upon the break of electric circuits in telegraphic, scientific and medical apparatus, and tending to burn away or oxidize, contact points; while in the case of the two wire induction coils its effect was to reduce the spark passing between the terminals of the secondary; and many have been the expedients, wise and otherwise, which were devised for its banishment. Many of these were patented; more were not; inasmuch as the fever for

7. Transactions of American Phil. Soc. Vol. VI. pp 303–337, Nov. 2, 1838. Silliman's American Journal of Sience, March, 1840, Vol. 38, pp. 209–243. Scient. Writings of Joseph Henry, Washington, 1886, Vol. 1, p. 108.

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patenting everything from a solar system to a thought had not then come into fashion.

Examples of this class of expedient are respectively:

British Patent, No. 12,772, September 20, 1849, granted to those old heroes of electric lighting history, Staite and Petrie, which has for its 18th clause, a mode of "preventing the spark when breaking contact in galvanic circuits. A thin platinum wire may still convey some portion of the current after the main circuit is broken, or a series of sufficiently long conductors may break contact one after the other." The preferred way, in plain English, was to connect a fine wire as a shunt round the break, and thus to furnish a closed circuit in which the self-induction circulated its current of breaking.

United States Patent, No. 33,269, granted to J. E. Smith, September 10, 1861, for a means of preventing the spark between the local points of a relay on breaking the circuit; shunting the break by a wire having two terminals dipping into a bottle of water.

Moreover as is well-known in the ordinary induction coil the action is emphasized by shunting the primary break by a condenser as first suggested by Fizeau[8].

This, as I shall point out later, is a real instance of the industrial utilization of self-induction.

Other early investigators in this line reduced the spark of breaking the circuit, by wire shunts also.

Although as I have stated, the recognitions of self-induction were mostly recognitions of an adversary, there were one or two early instances where the enemy was subjugated, and made to expend his energy usefully. The most notable instances of this are the single wire spark coils of Page and Callan[9] which were made especially with a view to exalt the self-inductive effects and with which metals were fused, and electrolytes were decomposed.

These were the forerunners of the spark coils used at the present day in electric gas lighting and comprising a single long coil wound to a suitable length upon a long core of iron wires.

There can, however, be no doubt that the principal attempts to make useful the counter-electromotive force of self-induction, and likewise the principal successes achieved, have been in the

8. Comptes Rendus, Vol. XXXVI. p. 418, 1853.

9. Sturgeons Annals, Vol. 1, pp. 290–302.

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line of controlling, regulating or modifying the original, initiatory, or primary currents from which it has been developed.

I have compared this to the transposition of a given number of battery cells.

This analogy is however imperfect, since in cells of battery we may for the sake of argument regard the E. M. F., as being practically constant. Certainly they will in no sense regulate themselves in accordance with conditions automatically, but the inductive resistance *will* do this. For it is dependent for its efficiency as a generator, upon the strength of current flowing through it. Therefore, if the current through it due to the impressed electromotive force from any reason falls, the counter-electromotive force will also diminish and thus will permit a greater amount of the initial force to act; or in other words will permit the impressed energy to become more effective. Suppose we have in the main circuit of an alternating dynamo, supplying a number of incandescent lamps in bridges uniting its mains, an adjustable resistance; and suppose the inductive resistance, which we may also regard as a counter E. M. F. generator, to be initially adjusted, so that all of the lamps burn brightly; then within limits of considerable range, the current will be kept steady even though the applied E. M. F. fall or rise, or though the external resistance of the circuit be varied by lighting or extinguishing lamps.

For if lamps be extinguished and their branch circuits be opened, the external resistance rises and the current falls. It is true that the reduced current has not now so many branches to divide through, and that therefore self-regulation even without counter E. M. F. might be expected, but in systems of considerable magnitude it is not found to act practically, as well as it theoretically should. But here the useful effect of our self-induction regulation comes into play; and since the current acting upon the regulator is lowered, it is caused to develop a counter E. M. F. of less value, and thus to oppose less energetically the applied E. M. F, which therefore is brought to a greater extent into action, to overcome the increased resistance, and to maintain the normal current for the remaining work. So, if the applied potential falls, the current in consequence falls with it, and the counter E. M. F. developed falls also, and enables more of the applied E. M. F. to come into action. And the converse is true, if the current in the circuit from any other cause rises. Such an ap-

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pliance would be still more convenient in connection with an arrangement of arc lamps fed by alternating currents, and connected up in parallel circuit, since the resistance of arc lamps would constantly be changing.

This has been so prominently brought before us by its most modern employment, namely by its well-nigh involuntary use in the distribution of electricity by means of alternating currents and transformers or converters having their primaries connected in parallel between the two mains of the source; and by the inductive resistance regulating device, patented by John Hopkinson, in England, August 3, 1881, No. 3,362; and in the United States, November 5, 1889, No. 414,541, that many persons have actually been led to believe that such use is really a new thing.

The employment in the regulation of electrical distribution, of counter-electromotive forces set up by the working currents themselves and proportioning themselves automatically to the work being done, is one of the most valuable and interesting features of modern electrical work; and, though such regulation requires to be supplemented by auxiliary arrangements, and though the belief of some that it could be attained absolutely without any waste has not been completely realized, still by availing ourselves of this feature we are enabled to control electricity with a facility and under conditions which otherwise would be unattainable.

The Hopkinson invention consisted in associating with an arc or glow electric light circuit employing alternating currents, a variable inductive resistance. This in one form was made by coiling a ribbon of thin sheet iron into a ring form, the different layers being separated by an insulating layer, and then by winding a number of coils of insulated wire on this ring, their adjacent ends being connected with plates between which contact plugs could be inserted, so that any number of the coils could be introduced or cut out from the circuit. Another form embodied the same principles, but had not a closed core. This form had a horse-shoe core made of an electromagnet formed of layers of sheet iron insulated from each other. The legs of the core are sorrounded with the coils, and the said core has an armature also made of insulated layers of sheet iron. In this form the armature is clamped down; but the regulability of the appliance is attained by moving the magnet core further into or

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withdrawing to a greater or less extent from the surrounding coils. The form first described, is in the British Patent shown as being included in circuit, with the two mains of a dynamo; incandescing lamps being in cross bridges between the said mains; while in another figure arc lamps are in parallel circuit with mains, an inductive resistance being included in each branch for each lamp and acting as an equalizer.

The iron core closed on itself to form a complete magnetic ring in which the lines of force are concentrated through the coil, and forced to cut all convolutions when exposed to reversals; the laminations at right angles to the currents, acting to facilitate magnetic change, to diminish hysteresis, and to prevent the circulation of eddy currents; and the insulation of the said laminations aiding in the latter function; all tend to show that this is a very highly organized appliance and is not only well adapted to produce a very high degree of self-induction, but combines most of the best arrangements tending to that end, and it is therefore not surprising that its invention and use made a strong impression upon the electrical mind, and caused a revival of the idea that regulation on these lines was capable of being accomplished, to use the words of the patent, "without wasting energy." Without materially wasting energy would perhaps be more strictly accurate, for by its use a small amount of actual resistance coil is enabled to do the work of a very much larger amount.

I have certainly no desire to detract from the great merit of this application, but an honest chronicler has no choice and must say what has been done, and it must therefore be stated that inductive resistances and other self-induction appliances had long been used both experimentally and commercially; no doubt often with but an imperfect conception of their mode of operation.

[9] Poggendorff's researches into the action of induction coils disclose a remarkable state of affairs for so early a date These show that one induction coil was employed to send a current through the secondary helices of two others. The first coil thus acted as an alternating generator, and the two others as inductive resistances.

9. Poggendorff's Annalen, Vol. XCIV., p 2 and London and Edinburgh and Dublin, Phil., Magazine, 1855, Vol. 10, 4th series. p. p., 136–137.

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The primaries of two induction coils were connected in parallel and also in series at different times. When, to quote Poggendorf's own words: "Two instruments (induction coils) A and B, were so combined that the current traversed the two primary coils one after the other, the induction coils (secondaries) however were separated and A was allowed to give sparks, whilst B remained unclosed and without a soft iron core; the introduction of the latter into B, weakened the sparks of A, and the subsequent metallic closing of B reproduced their former strength."

The proper arrangement of induction coils is then discussed and whether the primaries should be connected in series or in parallel circuit. It is shown that the latter way is the proper one, and why. Then the paper goes on to say, "With respect to the cause of these phenomena it is no doubt to be sought in the extra or inner induction current. The outer induction current which is produced by breaking the inducing current has the same direction as the latter; whereas the extra current, which is at the same time excited in the induction wire, whose tendency is to weaken the first induction current, and the more so the stronger the extra current, which latter is especially strengthened by the soft iron core.

Consequently when the primary coils of A and B are connected one after the other, it is clear that the insertion of the soft iron core into that of B, will strengthen the extra current in that of A, and therefore weaken the induction current of the latter instrument.

By connecting the instruments side by side a closed circle is at once formed by them, and the extra current produced by the insertion of the soft iron core into B acts against that in A, and may therefore when both are equal completely neutralize it, when the outer induction current of A will necessarily be strengthened.

Without the circle formed by this combination, *i. e.*, in the wire leading back to the voltaic battery, the two extra currents act of course in the same direction and strengthen one another, in consequence of which the sparks at the current breaker are still very active."

These considerations of Poggendorff, show that even at this early period a great flash of light was thrown into the darkness which hitherto had obscured the reactions of self-induction, and though we have largely failed to use that light until quite re-

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cently, this is chiefly attributable to the same oft recurring reason, that there was really little call for it; hence it was soon hid under the bushel of the results of research on other subjects of more immediate interest.

The statement which I last quoted, brings me again to the application by Fizeau of the condenser as a shunt to the vibratory break, and to its operation.

[10]As shown by Lord Rayleigh, the condenser operates by producing electrical oscillations and in its action the spark at the contact breaker is greatly decreased and the spark between the secondary terminals greatly magnified, because at the break the condenser is virtually an inductive reservoir, being an electrostatic shunt. And being an electrostatic shunt, the energy it momentarily absorbs is returned reversely to the primary circuit, just as in the discharge of a secondary cell, and increases the inductive variation in the secondary circuit during the brief period of time immediately after the break. And as the electromotive force in the secondary is thus exalted it is not difficult to see why the condenser increases the sparking distance.

As early as December 6, 1862, a patent for cable working, No. 3,453, was taken out by C. F. Varley, which describes the use of a self-induction resistance. This patent says, "A second circuit from the cable to the earth independent of the receiving instrument is formed by means of a resistance coil with a large iron core. It may be advisable to connect the cable to earth through an induction coil consisting of a large bundle of iron wire, surrounded by a long length of fine wire, the action of which is as follows: On reversing the battery connections the induction plates (condenser) and battery combined, send a short impulse into the cable, which divides; one portion into the cable, the other through the induction coil to the earth. At the first moment, the iron of the core opposes the passage of the current, consequently during the first instant of time, nearly the whole force of the current is applied to the cable. As the iron becomes magnetized to its maximum, this opposition ceases, but the plates have been charged in the opposite direction, and there is no longer any current passing from them into the cable to maintain the magnetization of the iron; the demagnetization of which, induces a current in the coil, and discharges the cable. In this way each impulse is followed by a short impulse in the opposite direction.

10. Phil. Mag. Vol. XXXIX., p. 428, et seq.

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One of the figures of the patent, shows that the wires of the core are made long, and are turned back on all sides over the wire of the coil, so as to entirely encase it. This feature was in conformity with a previous British Patent, No. 3059 of 1856. The arrangement however clearly shows a use of a self-induction coil as a current controller, and indicates the function of a large iron core.

We next find the counter E. M. F. of self-induction coming into use in connection with fast telegraph systems. Arrangements for its use are shown in the United States Patents granted to Mr. Edison. These are respectively, No. 135,531 of February 4, 1873; No. 141,773 of August 12, 1873 and No. 147,313 of February 10, 1874.

The first and second disclose a shunt circuit including an electro-magnet connected round the receiving instrument of a chemical telegraph. The first, also shows a leak to earth from the line, which leak includes an electro-magnet. In both cases the object is to utilize the discharge current developed by the electro-magnet in the regulation of the operation and to produce sharp and clear signals.

The third, describes the use of electro-magnets in shunt circuits round the transmitting and receiving instruments of an automatic telegraph system and is said to be an improvement on the first. A number of electro-magnets are shown and by means of a switch one or more of these may be introduced. In other words the inductive resistance is here adjustable, and is operated by breaks, not by reversals.

British Patent No. 3,935, Nov. 14, 1874, to Alexander Melville Clark for a chemical copying telegraph, uses induction and other coils to clear a line by the self-inductive counter E. M. F. By the decrement or cessation of the impulse, (as the patent states) the strongest depolarizing effects are produced, and the line is successfully cleared.

Next come four other patents to Thos. A. Edison. These are U. S. Patent, No. 168,243, of Sept. 28, 1875, for an automatic telegraph. This, as in the previous cases, employs an electro-magnetic shunt.

U. S. Patent, No. 168,325, of October 5, 1875, Duplex Telegraph. This is an excellent example of self-inductive regulation. The counter E. M. F. is developed from electro-magnets in a changing electric circuit, and the coils have cores closed on themselves.

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The next two, No. 173,718, of February 22, 1876, for automatic telegraphy; and No. 178,221, May 30, 1876; Duplex Telegraphy; involve no new principles and are like the preceding ones.

[11]Much information regarding the subject and further examples of its practical application can be found in a particularly able paper on "Shunts," read by William H. Preece, before the Society of Telegraph Engineers in 1887. The subject of the counter E. M. F. developed in electro-magnets is discussed, and the increase of the same, when the iron core is endless, is determined and pointed out; a good many instances of the practical uses of the self-induction shunt are described.

U. S. Patent, No. 207,724, of September 3, 1878; granted to Thos. A. Edison for a Duplex Telegraph, shows an electro-magnetic coil and closed magnetic circuit core placed in each branch of a Wheatstone Bridge duplex telegraph, to counteract by its counter E. M. F. of self-induction the discharge of the electro-magnets in the bridge circuit. In Culley's Handbook of Practical Telegraphy, London, 1878, p. p. 303 to 304, also p. p. 305 and 411 the regulation of currents by inductive resistances is considered.

In the first instance, the counter E. M. F. of an adjustable series of electro-magnetic coils is used to delay the discharge of a condenser in a duplex system. This is closely analogous to the function of the Hopkinson device, and is very suggestive. The reference on page 305 states that "static discharge can be entirely compensated for by the use of an induction coil, or a series of electro-magnets instead of a condenser."

U. S. Patent, No. 227,039, of April 27, 1880, to Muirhead and Winter, for a Quadruplex Telegraph, describes electro-magnetic shunts for reversing keys and relays, which are to counteract by their discharges electrostatic retardation. The specification says, "The electro-magnets may be of the well-known closed horse-shoe form, or they may consist of a single rod of soft iron with flanges of soft iron and a cylindrical casing of iron closing over the wire and connecting magnetically flange with flange.

U. S. Patent 231,904, September 7, 1880, to Joseph E. Fenn, Duplex Telegraph, uses an electro-magnetic generator of counter E. M. F. in the line circuit to counteract effects of discharge. It is made with a closed magnetic circuit, a separate coil being on

11. Journal of Society of Teleg. Engineers, London 1877, p. p. 40-69.

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each leg of a multiple pole core; several of these poles are made with yokes, and the combined yokes can be made magnetically continuous or discontinuous at will by means of iron plugs which can unite the different sections of core.

A book published in 1880, by Louis Schwendler, and entitled, "Instructions for testing telegraph lines, and the Technical Arrangements of Circuits," Vol. 2, p. p. 144-147, gives a description of an electro-magnetic shunt and its operation. It is made like an ordinary electro-magnet, but has an adjustable wedge-shaped armature in contact with the cores. This of course operates by utilizing the counter E. M. F. of self-induction which develops currents that circulate through the shunt, and sharpen the signals.

In telephony also, as in other fast systems employing rhythmical currents, the counter E. M. F. has by no means been idle. As in telegraphy our early acquaintance with it was an unpleasant one. Many of the earlier telephone lines connected with a number of stations, and at each station there was of course an electro-magnet to operate the call. In some cases this was a telegraph relay, and in other cases a bell magnet But in either case it was found, as indeed might have been anticipated, that the telephone currents had a decided repugnance to pass through the intervening electro-magnets on their way from one station to the other. To quote the graphic words of one of the patentees of devices intended as remedies for this trouble, it was found that electro-magnets were to a large extent "opaque to telephone currents."

Of course this is due to self induction. The resistance of the line or the magnet coils had little or nothing to do with it. The convolutions however had, since it is clear that the electromotive force of the self-induction was proportional within certain limits to the number of convolutions.

The same difficulty appeared also in exchange work, where between any two connected lines was interposed an annunciator, to give from either end station a disconnecting signal. Several devices have been suggested for the removal of this difficulty and some of them have been patented.

Elisha Gray shunts the several interposed magnets by condensers: vide United States Patent, 203,264, of May 7, 1878.

F. W. Jones, attacking the same difficulty, shunts the interposed magnet by a non-inductive resistance controlled by the armature of the signaling magnet. See United States Patents, 238,399, of March 1, 1881, and 238,912, of March 15, 1881.

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Other devices have also acted to shunt the bell or annunciator magnets in different ways; and still other suggestions have been, to surround the iron core with a brass sleeve, or with a closed circuit consisting of one layer of insulated wire; but these last, while certainly reducing the retardation, reduce also the magnetic power of the appliance. And there is no remedy so effectual as the absence of the interposed electro-magnet.

The service rendered by self-induction in telephony, and that which still may be expected, fortunately will probably outweigh the ills which it introduces. In many switchboard installations for metallic circuits, the supervising telephones are looped or bridged across between the two conducting links which unite one of the two metallic circuits with the other, and their self-induction prevents a material loss of current. Where from some condition of the service such for example as the requirement of supervising both metallic and earth return circuits at the same switchboard it sometimes becomes necessary in bridging the telephones to attach an earth branch to the connecting link on one side of the instruments; in this case it has also been found necessary in practice to place coils containing iron cores on the other side of the earth branch, so that not only the resistance but also the self-induction may be balanced.

It has also been ascertained that many telephones can at different stations be placed across from one wire to the other of a metallic circuit without any perceptible diminution of the effect at any one of them. This is one of the most important results of self-regulating attribute of self-induction.

Perhaps, however, the most valuable instance of turning an electrical enemy into an electrical ally, is the way in which by the proper use, construction and arrangement of electro-magnets, a plurality of either telephonic or partially telephonic and partly telegraphic messages may be transmitted over the same circuit at the same time.

The pioneer in this kind of work was C. F. Varley, who as early as 1870 took out a patent, No. 1,044 in England, for a combined simultaneous ordinary Morse and harmonic Morse transmission over the same wire; in this system the straight Morse was worked through electro-magnets, while the harmonic branches were led off from the main line from points outside of the electro-magnets.

Carrying on this line of invention, Mr. Van Rysselberghe of

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Belgium, and Dr. Rosebrugh of Toronto, Canada, have worked out systems whereby telegraphy and speaking telephony can be at the same time operated over the same circuit.

Since, however, there is enough in either system to fill up a paper devoted to them exclusively, and since this paper is already too long, I find it impossible here to describe them in detail, reserving this possibly for some future occasion.

Self-induction has also been caused to aid in eliminating the disturbing results of extraneous induction caused by parallel circuits, as in the United States Patent of Mr. Edison, No. 203,019, of April 30, 1878, where a telephone circuit is freed from external influences by combining it with an induction coil connected with the disturbing circuits in such a manner that the direct disturbances received in virtue of the parallelism of the contiguous circuits is neutralized by an equal and opposite induction received also from them through the induction coil. This, however, is not a practical expedient.

Closely analogous to the self-inductive regulation of which I have been speaking, is that upon which the efficiency of an electro-motor depends. This was first observed by Jacobi[12] who says:

"Experimenting on the magnetic force of a bar of soft iron, I sometimes found considerable differences for which I could in no way account. I was curious to know if these differences proceeded from the nature of the iron, or from the weakening of the electric current produced by a voltaic pair of half a foot square of surface. For this reason, I placed in the circuit, a galvanometer so distant as not to be affected by the direct magnetism of the bar. I was much astonished to see the needle recoil on placing the armature and advance on removing it, for it was the first time I had known the double quality of the connecting wire, viz., that of constructing the voltaic current, and at the same time representing an ordinary wire subject to the action of a magnet in motion. The spiral producing a magnet by the voltaic current is at the same time a magnetic electrical spiral in which a magnet is placed.

Hence the solution of the uniform velocity of the magnetic machine. For being set in motion by the magnetizing power of a voltaic current it represents simultaneously an apparatus composed of magnets in motion and capable of producing a magnetic

12. Sturgeon's Annals of El'y, 1837, Vol, 1, pp. 408–419.

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electrical current in a direction opposite to that of the voltaic current."

Jacobi in a subsequent paper, practically elucidated the principles of the operation of counter E. M. F. in electro motors, even as now understood, although he possibly did not state them as we now would. But he clearly showed that a motor may be regarded as a dynamo acting to develop an electromotive force, opposite in direction to that acting upon it, E. That the resultant force was of course E-e, and that this together with the resistance of circuit determine the strength of the current. That the motor utilizes C e of the electrical power supplied C E; and he furthermore showed that the power developed by the motor C e, is at its maximum when e equals one half E.

It may be thought by some that considering the title of the paper the principal utilization to which I have referred, viz., the use in regulation of systems of alternating currents operating converters should have been discussed. It does not seem to me that it is necessary; this has often been done, and will again often be done by others much more competent than myself to handle the subject. But it does seem right that one should be found to give due credit for those who in the same line of thought are "not lost, but gone before," and I am glad that I am in a position so to do.

There seems little need for me to cite any more instances, showing that like nearly all new arts, the art of regulation by means of self-induction and of otherwise usefully employing the counter E. M. F. due thereto, is not *quite* new, and that while we can congratulate ourselves upon the achievements of the present, we should not fail to respect the foundation layers of the past, for of a truth, there were giants in those days.

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# LIFE AND EFFICIENCY OF ARC LIGHT CARBONS.

DISCUSSION OF LOUIS B. MARKS'S PAPER AT THE GENERAL MEETING, BOSTON, MASS., MAY 21, 1890.

(*See page* 175 *ante.*)

THE CHAIRMAN, PROF. ELIHU THOMSON:—I am sure we have all listened with great interest to the valuable paper of Mr. Marks and we hope that this subject, which is undoubtedly an important one, will elicit other opinions from the members. The paper is now open for discussion.

MR. G. W. BLODGETT:—I have been much interested in Mr. Marks's paper. But my experience with three or four isolated plants of the Brush system has been somewhat contrary to Mr. Marks's experience. He said, if I understood him rightly, that a very hard carbon is the best for a low tension system, and a very soft carbon for a high tension system. My experience with the Brush lamps has been just the reverse. I have got the best results with a very hard close grained carbon, plated with a thin plating of copper which seems to give better results than a bare carbon, or one heavily plated. He spoke of the difficulty of using the incandescent lamp in the photometer as a measure of the arc lamp. I presume those difficulties are quite as great, perhaps even greater, than he has said.

I had occasion recently to review some experiments which were made by Elston on a Siemens lamp in Berlin, lighting the Unter Der Linden. He states there that the difference in the color after a few hundred measurements, was of no consequence; that the photometer could be very exactly set using an incandescent lamp at one end and an arc lamp, or the reflection of it at the other end. He found that the lamps there, however, which were run at 2000 nominal candle power only gave from six to seven hundred. Mr. Marks also says that with low voltages a deep crater forms, while with high voltages no crater at all was observed. In a Brush lamp the craters which I have obtained were deepest when the machine seemed to have the highest voltage, although I got no accurate experiments.

He said also that with a high voltage and a small current there were mushrooms formed on the negative carbon, while with the large current they disappeared. With the old style of Weston

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lamp, which burns with a 20 ampere current and about 500 volts, these mushrooms were very much more troublesome, in my experience, than with a Brush lamp using about 10 amperes and a voltage of perhaps twice that amount. I would like to know whether any one has had a similar experience.

PROF. THOMSON:—On my own account, having had considerable experience with the arc light system and its development, I might say that I think that Mr. Blodgett has not probably understood perfectly what was meant in the tests concerning the mushrooms. As I understand it, the voltage was to be kept constant notwithstanding the efforts of the lamp to regulate. Then a diminution of current will produce a concave crater, according to my experience, and the little point or mushroom extends into that crater. Suppose for example we have the ideal arc (Fig. 1) If now we diminish the current and maintain the voltage, the upper carbon will come down gradually and get nearer and nearer the other carbon; that is assuming that the

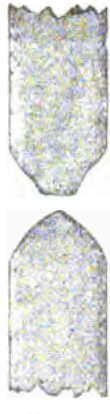

Fig.1

Fig.2

regulation of the arc lamp is allowed to take care of the voltage or assuming that we take a measurement of voltage and also of current. As we reduce the current and keep the voltage the same, the result finally will be that we get something like Fig. 2 with a much smaller crater and a mushroom.

MR. BLODGETT:—That is exactly what I have observed.

PROF. THOMSON:—That is, with a small current—reducing the current from 10 amperes to 5.

MR. BLODGETT:—I don't know about that. The lamp regulated itself.

PROF. THOMSON:—Let us take the other case, not separating the carbons; we will find that the voltage then will drop and will finally build up a heavier mushroom and much widened crater. That is the condition spoken of, allowing the current to increase without the voltage being maintained constant. In fact, I have

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carried currents of such force through carbons that the crater was over the whole end and the mushrooms built up in the form shown in Fig. 3. so that we have nothing but a layer of vapor between. It must be said, however that of course in this case we have a hissing arc. We have not the perfectly developed arc. The perfectly developed arc, in my judgment, implies about 40 to 50 volts and no hissing A remarkable fact, however, in that connection, is that with certain carbons it is possible to actually keep the current say at 10 amperes and bring the carbons almost into contact without a trace of a hiss. I have often noticed this which is, however, a peculiarity of what are called cored carbons. They are made with a soft graphitic core, (Fig. 4.) which apparently vaporizes with great ease and enables you to bring the carbon down with care so that no hissing is produced; but if you do it suddenly you may provoke hissing. I think one of the most interesting phenomena found in arc lamps is that of

Fig.3

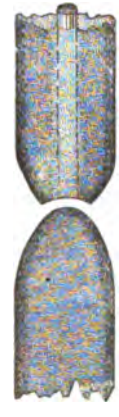

Fig.4

hissing. We have not yet found out what it is due to. But I think I can show an analogy which may point out what it is, or lead us to it. Hissing is most vigorous, so far as my experience goes, in carbons of coarse grain and it is more easily provoked in carbons of very coarse grain, especially when they are brought together. Now it is an old experiment in chemical operations to sublime sal-ammoniac in a dish. Sal-ammoniac gives off vapor when it is heated. If you do it vigorously and rapidly, you will hear the sal-ammoniac hiss and fry; but if the heating is applied moderately and slowly, there will be a gentle sublimation without noise. That leads me to think that the electrolytic vaporization, if we may call it that, that is the changing of the positive carbon into vapor, when this is too vigorous, or is so vigorous, as it were, that each little particle of carbon, when it gets into the crater, explodes, then you have a hiss; but if it actually vaporizes as water does when it is kept hot but not boiled, you have the ordinary quiet arc.

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There is another point in regard to that matter. I say that sal-ammoniac illustrates the effect. Now we find with the cored carbon that the inner core is more volatile. It exposes more surface on account of the fine grain, and the hissing of very fine grained carbons, whenever they hiss, is not so harsh. With retort carbon, such as carbons were made of years ago, very dense in grain and very fine, the powdering was so done as to give an almost impalpable powder. The carbons generally formed a rather smaller crater than the modern carbons, and I have known them, when they were just on the point of hissing, to take up a very musical note—sometimes even whistle—and the whistling of a carbon of that kind is the same thing as hissing. It is so uniform in grain that the little explosions have a note.

In regard to the structure of carbon as brought out in the paper, I may say that I had occasion years ago to look into the carbon question, and we found, in the years 1881 and 1882, that it was absolutely impossible to get satisfactory carbons for high-potential systems. It was a matter of discussion whether we would not be forced to manufacture the carbons that we should use. I found that in looking over the carbons the best results were obtained with moulded carbons on high tension work, and that forced carbons or squirted carbons could not be made at that time to maintain a steady arc. Their efficiency was low. If they came anywhere near being right they were still liable to the moving about of the arc and flaming, far more than the moulded carbons. That led me to examine the structure of them somewhat and I found that on breaking the moulded carbons—simply making a fracture anywhere, and examining the moulded carbons as compared with the forced carbons there was an entire difference of appearance at the ends. The moulded carbons had a glistening fracture when looked at straight on and a dull fracture when looked at across; whereas, the forced carbons had a glistening fracture viewed from an angle and a dull fracture looked at on end, showing that the lay of the particles was entirely different in the two cases. The process of forcing the carbon seems to lay the particles in line so that they present their edges to you when you look straight on—consequently having a flaky nature. The fact is the carbon, being petroleum carbon, is formed in flakes in the die retort. The flakes when they are forced out by the press enter on edge and lie up sidewise and come forward that way, and that carbon has the peculiar grain mentioned; but in the moulded carbon, where the pressure is applied laterally, the particles can lie in any direction, and consequently some are presented to you flatwise, and when you look on the end of the carbon you see some facets; and I found by tests of hundreds of the very best carbons, that the one that was moulded and gave me the brightest, cleanest fracture on end and a simple dull fracture the other way gave the best arc. Then it would seem almost as though this good effect requires that

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evaporation should take place from the side of laminae of the carbon; that when the grain was sticking out as in the forced carbon you could not rely on the stability of the arc. It would leave one point of discharge and and take up others.

There is another fact in connection with arc work which probably accounts for the flaming to some extent. If we take a carbon and elongate the arc so that it tends to flame, we find that the arc plays between the ends and blunts the edges of the crater, as though there was no boundary line for the discharge. Consequently the heated air rushing up may carry the arc over the edge and make it overlap a little, because above there is carbon full of gases and the arc naturally takes the more volatile materials Why? Because there is with the more volatile portions perhaps less counter-electromotive force developed; less energy to be

Fig.5

Fig.6

absorbed there in making vapor from it. Consequently the arc flames and runs up the side (Fig. 5.) pointing itself always on the negative.

Another peculiar thing about the arc I noticed some time ago, and I find that Professor Fleming has recently investigated the same and other phenomena. You can readily have one negative in an arc and any number of positives, (Fig. 6.), but you cannot easily have one positive and any number of negatives form the same arc. You may bundle up sticks of carbon close together and leave them slightly separated and place a carbon opposite and you may have current running out of several of the positives to reach the negative, but you cannot have several negatives feeding a single positive, as it were, in multiple without special arrangements to secure the division of current at the nega-

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tives. In other words, the very fact that we have a crater means that we can have a great number of discharge points on the positive. The very fact that we do not have a crater or rather have a little point on the negative, indicates that we can only have one discharge point on the negative, or at least that one small space suffices for the current to pass. Otherwise the discharge would spread over and take up a larger area, at the same time.

Some of the most curious phenomena in relation to the effects of arcs burning are found in burning very large lights and I think that this is a subject which really requires some attention. I wish I had time to look into it. Take arcs burned with one hundred and fifty amperes or more and we find that the conditions for obtaining a quiet arc are much more difficult to preserve. The arc very easily gets into the unstable condition of hissing, and when it does it generally gives warning. I have seen it give warning about the time it was going to do that and sometimes fail to do it. We will suppose that a quiet arc is burning with a

Fig.7

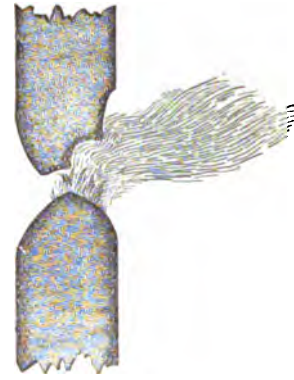

Fig.8

crater nine-sixteenths of an inch in diameter, and carrying a considerable current (Fig. 7.) The flame, of course, is considerable. There is a tendency to deposit carbon on the lower carbon. If the carbons are too near together the combustion is prevented and the carbon is deposited. But as I was saying the large arc will sometimes give warning of its tendency to hiss and generally begins at the negative carbon by the radiation of a series of striae of different color, and if they seem to reach near the positive, then you may be sure that the hissing has begun, because the fact is you will see the whole phenomena change, great masses will be cut out of the carbons and I have seen flames run off eight inches from the side of the carbon (Fig. 8.)—enormous roaring flames that could be heard all over the factory, and it is very difficult to quiet such an arc down again after it has once got started. Some of the arcs of large size now burned use cored carbon.

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In fact that kind of carbon has done much to make it possible to run large arcs quietly.

Another style of carbon is one whose section is that of a fluted cylinder, so that we get the body of carbon and yet keep the arc on the center. (Figs. 9 and 10.) This I believe was due to Carre, the well known carbon maker. If that were also cored it would give excellent results. I must say that very many of the things brought out in the paper are confirmed by my experience and I am very glad to see them recorded. They are brought out in a scientific way, based on measurements, and that is the proper way to do it. In working along with arc lights we pick up a little here and there and finally accumulate a certain fund of information, but it needs to be classified and arranged, and I am glad to see that in this paper it has been done. I think attention of that kind should be given to this very subject.

In relation to a number of other matters it is not necessary to

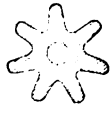

Fig.9

Fig.10

prolong the discussion. I should be very glad to hear from other members on the subject.

MR. MARKS: Mr. President, I would like to state in confirmation of what you said regarding the whistling of the arcs that I worked at this late at night when everything was absolutely quiet; that during the range of potential, starting a lamp from no voltage to a high voltage the sound varied in wave lengths it seemed to become higher and lower according as the voltage changed. The point in connection with the arrangement of the striae of the carbon in moulded and forced pencils are brought out I think clearly in Figures 9d and 12d in which you notice both forced pencils have parallel striations and also note that they lie in a longitudinal direction or in the same direction as the application of pressure used in the manufacture of carbons. The moulded carbons show the other instance.

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Prof. Thomson has brought out the fact that quieting the arc is difficult to do with a large diameter of carbons. I would like to know if he has ever tried the means of doing this by the application of extraneous force; that is, having a number of lines of force circulating around the arc in such a direction as to keep the arc in the centre. I have tried that with considerable success.

PROF. THOMSON:—I had that very arrangement one time, but it is a difficult matter to follow the arc and keep just the right position. It is making a certain magnetic whirl around the arc and feeding it along the arc. If by that means you can hold the arc in the centre, the tendency to flaming, as well as the tendency to hissing, is modified. I am glad to know it has been done successfully. I did not make any considerable experiments in that direction.

I would simply add that in regard to the life of carbons that my experience has confirmed perfectly what has been brought out in the paper that it is rarely that you get carbons, positive and negative, that burn in the ratio put down in the books—1 to 2. It generally departs from that relation considerably, and of course with low tension systems much more so, simply because of the plating action which saves the lower carbon. The carrying of carbon over and building up of the negative prevents the lower carbon from wasting by combustion when it is receiving constantly large accessions of new material. Consequently the positive carbon is the one that is consumed. It has to furnish the material to burn; while the negative is preserved by deposition.

MR. MARKS:—By having a suitable range between the plus and minus, it is very easy to obtain the plus and minus carbon that would burn away exactly at the same rate.

PROF. THOMSON:—By using a very soft under carbon and hard upper carbon.

MR. MARKS:—Of the same diameter.

PROF. THOMSON:—By focussing lamps geared at the same rate.

MR. O. T. CROSBY:—I should like, as a matter of information, as I am not very familiar with this branch of the work, to know whether it is perfectly safe to calculate the total life of the carbon by a rate determined from observation. In other words, is the rate of consumption uniform throughout its whole life? What you said concerning the building up of the lower carbon makes my doubt a little stronger; although I am not posted in the matter—because we appear to be building up a new pencil all the time, whose structure and consequently whose rate of consumption need not be the same during the different portions of its life as of any given portion.

PROF. THOMSON:—As to this particular case of building up a new structure, by carriage and deposition of carbon on the

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negative, the way this added carbon is disposed of is not by combustion; the carbon pencil burns below the point of building and the piece above tumbles out. (See Fig. 12.) It is wasteful of carbon, because in this particular instance it simply protects the ends—until this dropping out action occurs—from being burned. This merely excludes the oxygen at the point and lessens the rate of burning. I think it would be possible with a perfectly formed arc, that is, with an arc burned at 45 volts, to calculate with most carbons the rate from one hour's burning. That is, the variation would not be very great. If the pressure in the moulding is uniform and in the forcing also, the structure may be considered fairly uniform. It would not be possible, however, to take the same make of carbons and several batches coming out at different times and calculate from the rate of one carbon taken out of one batch what would be the rate of all the batches, because they do vary and the carbon manufacturer cannot altogether help it.

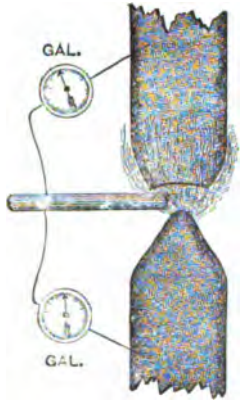


Fig.11

Fig.12

## Note A with Fig. 11.

(Communicated by Prof. Thomson.)

This concerns electro-motive force differences between the arc flame and the respective carbons, positive and negative. This difference can be observed easily by inserting a small carbon rod into the arc with a voltmeter connected from the rod to the positive carbon for determining the difference of potential between the positive carbon and the flame, and also a voltmeter connection between the inserted rod and the negative carbon. Nearly the wholee lectromotive-force difference will be found to exist between the positive carbon and the inserted rod. This

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indicates that most of the work done in the arc is done in the positive electrode or where the current passes from the positive carbon into the gas or at the crater itself, which is the dividing line between them. It is natural, therefore, that the arc should spread itself out on the positive carbon and acquire a considerable area over which this work is done while at the negative carbon it should concentrate itself, as very little of the work is done there in the passage of the current from the gas stream to the negative carbon.

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MR. MARKS:—I made a number of transverse tests of carbons from different batches and found that in one batch of carbons the ultimate strength was 41 3-10 pounds; while in another batch sent on some time later the ultimate strength was 48 pounds, showing that the carbons were not absolutely homogeneous.

PROF. W. A. ANTHONY:—The quality of the material, the temperature of baking, all those things, of course, make a difference in the carbon produced, and it is very difficult to control them all in such a way as to produce an absolutely uniform product.

I would like to say one word in regard to photometric tests. The remark was made here that it was found after working a number of hours on a photometric test that the color of the light made no difference, and while I have no doubt that in making photometric tests with arc lights by comparison with incandescent, one would become accustomed to the difference in color in such a way that while you get uniform results continuously, if you let some other man come and take the photometer with that conditions of things, I think the result would vary entirely. Probably the other man would go on and in the course of a few hours he would get so that he could get uniform results for himself. There would be a personal equation in there that would be a pretty serious matter.

PROF. THOMSON:—I think that Prof. Anthony's remarks are very apt indeed. People undoubtedly have a different color scale, some people seeing far up in the violet and not so far down in the red. I have seen one case in which the color scale of the individual was simply yellow.

MR. FRANKLIN L. POPE:—I would like to ask Mr. Marks if he ascertained the character of the raw material that was put in the different makes of carbon with which he experimented; whether they were of the same or different sources such as pulverized carbon, or petroleum, or natural gas and the like?

MR. MARKS:—The manufacturers were very reticent in regard to that matter. I obtained information from two of the companies. I may state that the product of the second distillation of petroleum was used by one of them as the crude material, and a

given amount was measured out and one-quarter of its weight of pitch was added. This formed the mass which was moulded into sticks. In another case I understood that one-third of the weight of pitch was added. This information was received from the factory. I cannot vouch for it. I have never worked in any of the carbon factories, and I would not like to commit myself.

PROF. THOMSON:—I think it is safe to say that most carbon manufacturers to-day use petroleum carbon. Formerly some of them used the gas retort hard carbon, but it is so hard to grind and impure—iron and ash of coal naturally working into it—that it is only suitable in any case for use in low tension systems. Perhaps some of the forced low tension and very hard carbons are still produced from gas carbon, but we never found an instance in which such carbon was used successfully in high tension systems, on account of the volatile material—the ash—causing changes of color and causing the arc to "flame around," as we would call it.

MR. MARKS:—The statements was made a little while ago by one of the members that forced carbons are in some cases adaptable to high tension systems. I tried all the forced carbons that I could possibly find and I have not come across any that will give anything like as steady a light. There is the spluttering and hissing and flaming that Prof. Thomson alluded to, and besides this the light is apt to go out at times.

PROF. THOMSON:—That accords perfectly with our experience. We have adopted moulded carbons for high tension work, and any one simply presenting us with a forced carbon and saying that it was for our work, would be told at once we did not wish to see it. We have been through that experience so often that there is no use in looking at it.

MR. F. L. POPE:—I think it would be very desirable if some one could make a study of the battery carbon as Mr. Marks has the arc light carbon. I would like to make that suggestion, and if any one desires to follow it up I think the results would be of very great value.

PROF. THOMSON:—That is an apt remark indeed. I am very much surprised that no one has done it in relation to battery carbons. The quality of battery carbons could undoubtedly be brought to a high plane by due attention to materials, making, etc.

MR. F. L. POPE:—I would say in relation to that matter that I was asked to make a test of a battery carbon said to be made of sea weed carbonized. I obtained very good results from it indeed, perhaps better than with any other form of carbon that I could get hold of.

PROF. THOMSON:—I can say in seconding that, that I was asked to make a test of arc light carbon made from sea weed carbon and I obtained very poor results from it. But I can readily

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see that the conditions were altogether different. The battery carbon requires to be porous to take up gas. I suppose it was an open circuit battery—sal-ammoniac—Leclanche?

M. F. L. POPE:—Yes.

PROF. THOMSON:—And therefore required to absorb oxygen from the air, and the very absorptive power of the carbon was just the condemnation of it in relation to use in arc lights where you want the most thoroughly carbonized material you can get and as little absorbent as possible. If there is no further discussion of the paper just read we will take the next in order—a paper by Prof. Edward L. Nichols, of Cornell, entitled "Note on a New Photometer."

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*Read before the General Meeting of the American Institute of Electrical Engineers, Boston, Mass., May 21st, 1890.*

# NOTE ON A NEW PHOTOMETER.

BY DR. EDWARD L. NICHOLS.

Methods of photometry which take no cognizance of differences of quality are so ill adapted to the study of sources of light which differ from each other widely in temperature, that the introduction of some instrument by means of which both the character and the intensity of an illuminant can be readily determined, would be a desirable adjunct to the equipment of our photometer rooms.

The instrument which it is my purpose to describe has been designed to meet this need. Existing types of the spectro-photometer may be made to give good results, but they are expensive instruments and so difficult to use that it is only in the hands of observers of considerable experience that accuracy is assured.

The new apparatus, the "horizontal-slit" photometer, is in point of fact a spectro-photometer in which the polarizing device is entirely done away with. In it the extremely simple principle of the Bunsen photometer is applied successively to the various regions of the visible spectra of the source of light which are to be compared. A direct vision spectroscope of Browning's form is attached to the usual car of a Bunsen photometer, from which the disc and mirrors have been removed. The optical axis of the collimator is horizontal and at right angles to the photometer bar. The slit is horizontal and lies in a straight line, joining the sources of light, which are set up in the usual manner at the ends of the bar. The bar itself is preferably of considerable length (in the case of the one upon which the original instrument under consideration was mounted, it was 500 c. m. long) and should be divided into 1,000 equal parts.

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In front of the spectroscope slit are placed two right angled prisms of the same size and made of the same glass (see Fig. 1.) Their vertical adjacent edges bisect the slit, and light traveling from either end of the photometer bar is totally reflected by them and enters the right or left hand end of the slit in a direction parallel to the optical axis of the collimator tube.

The two sets of rays thus gathered into the spectroscope from the lights at the end of the bar are vertically dispersed by the direct-vision prisms and appear in the field of view as two vertical spectra standing side by side. Equal wave lengths are in the same horizontal line and any desired region may be brought into the centre of the field by an angular movement of the ocular telescope. The telescope moves along the arc of a suitably divided semi circle, to which it may be clamped by means of a set-screw. Wave lengths corresponding to the various circle settings are determined once for all, by observation of the more prominent of the Fraunhofer lines.

When the instrument, thus mounted, is placed at the middle of the photometer bar, between lamps which are identical in intensity and quality, the two spectra are of equal brightness throughout, wave length for wave length, from red to violet. If the two lamps differ in intensity but not in quality, the two spectra will differ in brightness by the same amount from end to end, and a position may be found upon the bar for which they will be identical throughout.

Under these circumstances, which are the only ones in which the Bunsen method in photometry is strictly applicable, the instrument may be used as a simple photometer, the setting for any wave length whatever giving the candle-power. For this purpose alone, viz., for the comparison of lights of similar character, the instrument offers certain manifest advantages over the various forms of the Bunsen photometer. In the course of the present paper I shall present some definite data concerning the relative sensitiveness of the two instruments when used in this way.

When the lights to be compared differ both in intensity and quality, ordinary photometric indications possess no perfectly definite significance. In this, which is the more general case, the relative brightness of the spectra of the two sources varies with the wave length. For each region of the visible spectrum, however, a position upon the photometer bar can be found at which the brightness of the two spectra in that region will be equal, and

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the observations thus obtained, when extended over the entire spectrum, will afford data by means of which the differences in quality of the two sources of light may be definitely expressed.

In a recent paper read before the Institute,[1] I have shown that for a considerable range of temperature at least, the ratio between the intensities of a certain wave length of the spectrum of glowing carbon, is identical with the ratio of candle-powers as determined by the Bunsen photometer. The wave length in question, determined from the intensity of the spectrum of incandescent lamps at various candle-powers, I had found to be approximately $\lambda=690$. M. A. Crova, in an important paper since presented at the late electrical congress at Paris[2] has pointed out the importance of this method of measuring the light from sources differing in temperature. The wave length which he has indicated for this purpose is $\lambda=582$, which belongs to a region lying slightly further toward the green than the one which I had adopted.

When the wave length of this region has been established beyond question, the photometry of lights which vary in color, will have been reduced to a definite scientific basis. Instead of attempting to use the Bunsen photometer in measurements to which it is not adapted, we shall be able to deduce the relative candle power of two sources of light from the comparison of a single wave length, and we shall be freed from the uncertainty arising from differences of colors and from the personal errors due to the independent use of the two eyes in observation. The determination of candle-power will then be an operation of precision, even when the sources of light to be compared vary widely in temperature. It is in the opportunity of performing such observations upon the photometer bar itself, under conditions which do away with many of the sources of error inherent in the usual methods of spectro-photometry, that the chief advantages of the new photometer will be found to lie.

The following set of observations, taken with the new instrument, may serve to indicate one of the uses to which it may be put. The data are taken from an investigation now in progress in the Physical Laboratory of Cornell University. The object in view was to compare the spectrum of a novel type of gas burner with that of an ordinary argand burner. The two lamps were

1. TRANSACTIONS OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, vol. 6, p. 183.

2. M A. Crova, *La Lumiere Electrique*, vol. 33, p 478.

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set up at the ends of a photometer bar five meters long, the bar, as already stated being divided into 1,000 equal parts. Readings were taken at six points in the spectrum. The purpose being to express the relative brightness of the two spectra, wave length for wave length, the intensity of that due to the argand burner was taken as unity throughout, and the brightness of each region of the spectrum of the flame under investigation was obtained in terms of that of the corresponding region of the spectrum of the argand. The results are given in Table 1 :

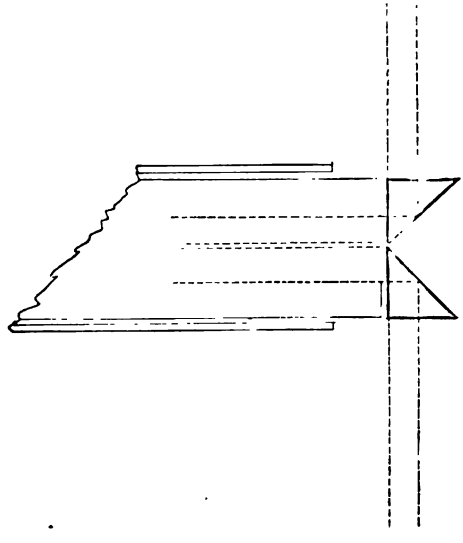

FIG. 1.—A NEW PHOTOMETER.

TABLE 1.

Comparison of the spectrum of a Welsbach burner with that of an ordinary argand burner, by means of the "horizontal-slit" photometer.[3]

| Color. | Wave length | Light-ratio Welsbach / Argand. | Probable error of a single observation. |
|---|---|---|---|
| Red | 702 | 0.709 ± .017 | 2.45% |
| Yellow | 589 | 1.476 ± .017 | 1.14% |
| | 558 | 1.760 ± .023 | 1.34% |
| Green | | | |
| | 500 | 2.395 ± .047 | 1.99% |
| Blue | 466 | 2.738 ± .036 | 1.30% |
| Violet | 439 | 3.090 ± .073 | 2 35% |
| | | | 1.76% (average) |

3. From observations by Miss Ida M. Hill.

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Ten observations were made in each region.

I introduce these measurements here simply as an illustration of one line of work to which the instrument under consideration is adapted. A full description of the research of which they form a part, and which covers many other questions pertaining to the very interesting class of lamps with which it deals, will doubtless be published in due time.

As will be seen from the column of probable errors, the sensitiveness of the instrument is greatest in the region of the D line ($\lambda$=589) and least in the extreme red and violet, where the light intensities are small.

A set of ten determinations made by the same observer with the Bunsen photometer, gave for the total light-ratio of the two lamps:

$$\frac{\text{Welsbach}}{\text{Argand}} = 1.701 \pm .015$$

The probable error of a single observation in this series amounted to 0.89%, a value somewhat smaller than that obtained with the new photometer in the yellow of the spectrum.

The number of observations is too small to afford a close estimate of the relative sensitiveness of the two instruments, but the results suffice to show that the "horizontal-slit" photometer does not differ appreciably in accuracy from the Bunsen photometer when the latter is used in the comparison of flames of the same color.

When it comes to the measurement of sources of light that differ widely in temperature, the comparison is decidedly in favor of the "horizontal-slit" photometer, the sensitiveness of which is not affected by differences of color. The error of the Bunsen photometer in candle-power measurement of the arc light, for instance, calculated from ten observations recently made upon the same photometer bar, the reference standard being an argand gas burner, was 2.65% (probable error of a single observation), a value more than twice as large as that of the "horizontal-slit" photometer.

A comparison of the performance of the new photometer with that of a polarizing spectro-photometer of the type which is commonly recognized as affording the highest degree of accuracy, is likewise decidedly in favor of the former. Taking as a basis eight observations made by Mr. Franklin and myself in the study

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of a bat's wing gas burner,[4] the observations covering eight regions of the spectrum, I find the error of a single observation, in the various regions to have been as follows:

TABLE 2.

*Probable errors of a single observation with a polarizing spectro-photometer, calculated from sets of ten observations upon various portions of the spectrum of a gas flame.*

| Wave lengths. | Probable error of a single observation. |
|---|---|
| 753 | 7.9% |
| 668 | 4.9% |
| 608 | 4.5% |
| 557 | 5.4% |
| 518 | 6.4% |
| 492 | 7.0% |
| 468 | 3.0% |
| 450 | 2.4% |
| | 5.2% (average) |

The measurement of a fluctuating illuminant, such as the gas-flame, is a line of investigation by no means adapted to exhibit any photometric instrument at its best; but as the errors of the horizontal slit photometer, already given, were calculated from sets of ten observations upon such flames, I have selected for comparison similar sets of ten upon sources of the same character.

The averages, viz.:

Error of horizontal-slit photometer, 1.76% (average for spectrum),

Error of polarizing spectro-photometer 5.20% (average for spectrum),

doubtless afford a fair indication of the relative performance of the two instruments in this peculiarly trying line of work.

At the last annual meeting of the Institute I had the privilege of presenting a brief study of certain personal errors pertaining to the use of the Bunsen photometer. The particular class of errors to which attention was called in that paper[5] are undoubtedly obviated by the use of the horizontal-slit-photometer; what new ones the latter instrument may introduce remains to be determined.

4. *American Journal of Science*, vol. 38, p. 100. See also TRANSACTIONS OF AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, vol. 6, p. 177.

5. TRANSACTIONS OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, vol. 6, p. 335.

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## Discussion.

Mr. F. A. C. Perrine:—I beg to ask Doctor Nichols how he calculates the light from the illumination given in different parts of the spectra? Do you compare it with the yellow light?

Dr. Nichols:—I do not know whether I fully understand the gentleman's question. The point is this—that if you take an arc light the intensity of which the Bunsen photometer shows is ten times greater than the incandescent lamp; and then take the spectrum of the arc light and the spectrum of this incandescent lamp and place them side by side, it will be found that in the region of yellow these spectra are as ten to one, and having once set up a standard of that kind you can test relative candle powers by comparing this portion of the spectrum only. I do not think this standard wave length has yet been determined with sufficient care. In a paper which I read before the Institute somewhat more than a year ago[1] I explained this matter more fully. I do not know what this particular wave length depends on, but it is possible to find it, and having found it the setting of the photometer for different qualities of light becomes as simple as the setting of a Bunsen photometer for lights that are just the same.

Prof. Thomson:—As I understand it, if we simply have blue or green light to deal with, of course that is ruled out of the question. We cannot give them value in terms of the yellow.

Dr. Nichols:—I think it is probably true only of the spectrum of incandescent carbon. I am quite sure that this standard wave length is different for lights of different sources.

The Chairman:—If there is nothing further we will close the discussion and the Secretary has some announcements to make.

The Secretary read invitations from the Boston Society of Civil Engineers, and from the Union Electric Car Company, extending their courtesies to the members of the Institute.

Mr. Crosby:—Mr. President, I think some formal action had best be taken to recognize the kindness of the civil engineers in extending the invitation, although I do not see how it would be possible to accept it for any trip to-morrow, as the West End trip and the visit to Lynn will occupy the day. I move a vote of thanks, while we cannot, on account of pressure of time, accept any definite hospitality.

The motion was carried.

A recess was taken until 2.30 p. m.

## Afternoon Session.

The Chairman (Prof. Elihu Thomson):—I have the pleasure of informing the Institute that our newly elected President, Professor Anthony, will now take the chair. I have succeeded in prevailing on him to preside for the rest of the meeting. I

1 See Transactions. Vol. vi., p. 158.

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know of no one more worthy or more able to conduct the proceedings of the Institute than Prof. Anthony, and I will say in stepping down from the chair that I feel that I have not been able to do quite what I should have liked during the past year. I have presided at very few meetings, and it has been because I was busy and because I was not on the scene, and because it happened that when I was in New York the meetings would occur about two or three days afterwards So without further excusing myself I will give the chair to Prof. Anthony.

PROF ANTHONY :—Gentlemen of the Institute, I must say the announcement to me this morning just at the moment the meeting was called to order that I had been elected President of the Institute, took me entirely by surprise. I had come here with the idea that Prof. Thomson was to preside at this meeting in Boston, and it seemed to me that he was the proper man to take charge of it. I certainly did not feel as though I had any claims whatever upon the Institnte. I may say that I have been thoroughly interested in the work of the Institute. I have been interested in electric work for a great many years, and have been a member of the Institute for some time, and have been present at its meetings whenever it was possible for me to be. I have always kept watch of whatever was going on in the Institute, and have felt that a great deal of good was coming continually from these meetings. I thank you most heartily for the confidence that you have placed in me in electing me to this position. As I said before, I do not feel that there is any special reason why I should have been called to this place, and certainly you might have found some one else who could always be present at the meetings, or who had at least done more to deserve the honor that you have conferred. I certainly feel that it is a great honor to have been chosen by such a body as this to represent it.

We will now proceed to business. The first paper of the afternoon is "On the Limitations of Steam and Electrical Transportation," by Oscar T. Crosby, of New York City.

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*A paper read at the General Meeting of the American Institute of Electrical Engineers, Boston, Mass., May 21, 1890.*

# THE LIMITATIONS OF STEAM AND ELECTRICITY IN TRANSPORTATION.

BY O. T. CROSBY.

"Do you expect electrical engines entirely to displace steam locomotives on all railroads?" That is a question which has doubtless been propounded to many electrical engineers. Its answer has doubtless been made, in general, by wise reference to the boundless possibilities of direct production of electrical energy from heat, and to Bellamy's "Looking Backward" storage batteries.

To make some study of the boundary line dividing the province of steam locomotion from that of electric locomotion—under existing conditions of producing electric energy—is the the object of this paper.

In the light of present achievements I may state, without argument, the following propositions:

*First*—It is possible to construct motors capable of doing the maximum work required to-day in transportation.

*Second*—It is possible continuously to generate electric energy equal to the capacity of any number of such motors.

*Third*—At any desired loss and over any desired distance it is possible to supply by the running contact method, the necessary current, at considerable pressure, for the working of such motors.

Should there still be question in the minds of any, as to the value of the running contact method at speeds much higher than those commonly used, I may state that I have seen 75 amperes at 500 volts thus continuously supplied to a car moving at more than 110 miles an hour.

These premises being established, further discussion divides itself into three parts.

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*First*, as to the mere possibility, without reference to the economy, of steam and electric propulsion under given conditions.

*Second*, as to the relative cost of exerting, in a locomotive, any unit of power by electric, as compared with direct steam motors.

*Third*, as to the relative amount of power required by the two agents to transport a given paying load under given conditions.

In using the word steam, as above, I have in mind only the direct application of steam power on the tracks. The case of cable propulsion is not here compared, as that has, within its restricted field of application, already been compared with horse, steam, and electric power.

The limiting possibilities of locomotion may be understood by considering a prolongation of the lines of present practice in the direction, first, of loads handled; second, grades climbed; third, speeds attained; fourth, length of continuous runs.

Since the effect of grade, as compared with load, is simply to increase the tractive effort required for a given load and speed, it need not be separately treated, except that there has been some question of increase of adhesion, in the ground return method, which in extreme cases might appear as an advantage for electric propulsion. The matter is not of great importance, and I will refer to it only so far as to say that interpreting my own general experience and some special tests, the adhesion coefficient seems not increased in any practical degree by the mere passage of the current from wheel to rail.

The capacity of an electric engine, like that of a steam engine, to haul any given load, will be measured by the tractive effort possible to be produced and the relation between weight and adhesion for given track conditions. The ready multiplication of cylinders in the one case and armatures in the other, while maintaining mechanical unity as to drawbar division, and the ready coupling of distinct locomotive units, renders the whole question of capacity to exert a given horizontal effort, without regard to the time element, unimportant and indefinite.[1] It

1 As an interesting example of an unusual load in steam service. I may refer to one consisting of 156 loaded cars and two cabooses, hauled over the Mississippi Valley Railway, December, 1885. The load consisted of—

| | Pounds. |
|---|---|
| Cotton weighing | 3,226,000 |
| Cars weighing | 3,239,000 |
| Engine and tender weighing | 147,000 |
| | 6,612,000 |

Speed was about 10 miles per hour.

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goes without saying that, if desired, a single armature may be constructed capable of exerting as great a drawbar strain as any locomotive now in use.

As to limiting speeds, it is not easy to-day to make "an educated guess" either for steam or electric propulsion. The high figures for steam that have been recently presented, both from England and America, are higher than the limiting figures as they would have been given by many competent authorities only a few years ago. Eighty-six miles per hour in England, on the Northeastern Railway, eighty-seven miles per hour in this country on the Reading Railway, have both been reported since January 1, 1890. These runs are noteworthy, not only for the fact of unusual speed, but because, as shown by indicator cards in the English case, and as may be deduced from the consideration of the maximum cylinder power in the American case, the train resistances are far below the values that would have been predicted by even the most liberal of the received formulæ on the subject. The total resistance per ton, as per indicator card in the 86-mile run, was only 13.4 pounds. According to Searles's formula, adopted by Wellington, it should be 69 pounds, engine and tender being taken at 50 tons. The load of 347 tons was carried at 86 miles per hour by an expenditure of 1,065 h. p.—this on a level. The engine was compound.

Would it be possible to attain a speed twice as great, or say 150 miles per hour?

A driver 24 feet in circumference would require to revolve 550 times per minute in order to travel 13,200 feet per minute, or 150 miles per hour—this without slip. Since in the case considered the revolutions per minute reached 309, and since in the Reading case a much higher rate must have been reached, the drivers being smaller, and since on stationary engines a speed much above 550 revolutions per minute has been attained, it seems beyond question that from this point of view the supposed case is quite possible.

Considering the matter of steam supply, we are again brought to consider the whole matter of train resistances at all speeds.

Total resistance to motion should be sharply divided into two classes: the resistance due to motion through air, and that due to friction and blows between vehicle and track, and to friction and blows between parts of the vehicle.

For the most part those who constructed the formulæ now

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found in the text-books, worked on roadbeds far inferior to the best work of to-day, at speeds much less than those now attained and with wrong values for at least one of the species of resistance, the atmospheric. On this point I have recently been able to present as the result of experiments at high velocities, made by Mr. Benj. J. Dashiell, Jr., and myself, a formula showing the pressure to be a function of the first, instead of the second, power of the velocity, as ordinarily assumed. A convenient datum point may be given stating that at 100 miles per hour the pressure on one square foot, normal to the direction of motion, is 13 pounds, while proper shaping of the front may reduce this 6.5 pounds.

The absolute values given, while corresponding quite closely with those of received formulæ in the neighborhood of the velocities heretofore experimentally attained, depart widely from those assumed for velocities higher than 30 miles per hour, and calculated by the quadratic relation between velocity and pressure. Using the more trustworthy values, I have been able to separate more nearly than has heretofore been possible the atmospheric from all other resistances met at high velocities. Some inaccuracy still remains, by reason of the difficulty of obtaining exact measure of the resisting areas in a train, but I have been able by study of careful tests made by others on the New York Central and on English roads, to find that over the range from about 40 up to 80 miles per hour the tonnage co-efficient seems practically constant at 8 pounds. This, of course, applies only to first-class roadbed and rolling-stock. Whether this co-efficient remains constant at higher speeds we do not know. There is no reason to assume, as has often been done, that it increases with the square of the velocity, and on the other hand it will not be safe to assume constancy. From experiments made with a single 2.5 tons car at about 100 miles per hour, the tonnage resistance at that speed seems to be about 20 pounds per ton. Though this value seems quite high as compared with the eight pounds at 85 miles per hour, the difference is in large part to be explained by the poor condition of the track used for the experiment and a constant curvature which would call for about four pounds per ton. Until better evidence can be had it will be safe, at least, to assume a value of 20 pounds per ton, on a first-class track, with good rolling-stock, at 125–150 miles per hour.

Having made this necessary digression, we may return to the

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matter of steam supply, and state that by reducing weight and area, both to something less than one-half the original values in the 86 mile run, the same effort would produce the speed 150, instead of 86. The area cannot be thus reduced, but by assuming a greater reduction in weight—say to 100 tons, or to little more than engine and tender—maintenance of the higher speed becomes possible, with nearly the same steam expenditure as in the recorded case.

To attain that speed, from rest, might require such original weight of fuel and such length of favorable track as to make the feat practically impossible with steam. This leads us to inquire into the dead weight necessary for hauling, say one ton at different speeds.

Table I. gives the horse-power required for exerting the tractive effort for one ton at various speeds. at various efficiencies, with various values of cross-section per ton, and with the two agents—steam and electricity:

Column 1 shows speed in miles per hour from 20 to 140; column 2, corresponding tonnage co-efficient, or resistance, in pounds per ton, exclusive of atmospheric resistance. Columns 3 to 8 inclusive, show horizontal effort needed for overcoming atmospheric resistance under various assumptions as to area exposed per ton, from 1 square foot to 0.1 square foot per ton. The former figure corresponds nearly to the case of a heavy locomotive propelling itself alone. As load is put on behind it, other ratios are formed. Oblique surfaces are supposed to be reduced to equivalent normal surfaces. Columes 9 to 14 inclusive, show rate of work in horse-power per ton, for the various cases of area exposed to atmospheric resistance, efficiency of locomotive being taken at 90 per cent. Columns 15 to 17 inclusive, show horse-power per ton for the extreme and middle cases of exposed area, and for locomotive efficiency of 80 per cent. Columns 18 to 20 inclusive, show same for efficiency of 60 per cent. Columns 21 to 26 inclusive, show weight of coal and water per ton carried for one hour, assuming 5 lbs. of coal and 15 lbs. water per horse-power hour on a steam locomotive. The coal figure is very close to actual practice. The water figure is less, but makes allowance for scooping water at convenient intervals. Continuous scooping is not considered practical or economical. Columns 27 to 29 inclusive, show weight of steam locomotive and tender required to generate the required

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horse-power per ton, under the assumption of 100 pounds per horse-power and 90 per cent. efficiency. Only three cases of exposed area are taken; that is, one foot, one-half a foot, and one-tenth of a foot per ton. The weight of steam locomotives is not calculated for any other efficiency figure than 90 per cent., as this seems to be quite constantly attained or surpassed. The assumption of 100 pounds per horse-power is closely true for many good types of locomotive when working at speeds from 60 to 80 miles. At lower speeds this figure is too low, but it is assumed that for any ruling speed engines may be built of minimum weight for that speed. In passing through lower than ruling speeds, both electric and steam motors work at low output per pound of weight, hence the assumption of constant weight per horse-power will not introduce error materially affecting comparative results. At higher speeds than 80 miles existing engines would show less than 100 pounds per horse-power; but as their boiler capacity is reached at that speed, the necessary increase for any regular work would carry the weight figure to very nearly the figure given for the 60 to 80 mile running. Columns 30 to 32 show weight of steam locomotive and tender, plus weight of fuel and water, per ton hauled; also weight of load—freight and freight car—that may be hauled by such weight of motive power; the load figures being obtained by subtracting the motive power weights from 2,000 pounds. Columns 33 to 41 show corresponding figures for electric locomotives under the assumption of 60 pounds per horse-power, and at the three efficiencies; 90, 80 and 60 per cent. In 30 to 41 inclusive, weight of load is written first, weight of locomotive (plus tender, fuel and water for steam) being written below.

The 60 pounds per horse-power covers weight of containing car for motors. I cannot here go into detailed figures on this point, but believe that any investigation will find the figure safe, supposing always that the unit be, say 25 horse-power or more. I also know of experimental work now progressing under most competent direction, which gives fair promise of leaving this figure much too high. Columns 42 to 53 inclusive, show the *horse-power required to be exerted for hauling one ton of load, i. e.*, freight and freight car, the relation between these two being taken as the same for either steam or electric propulsion; hence not necessary to enter here. These columns apply to steam at 90 per cent, and to electricity at 90, 80 and 60 per

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cent., and for the three cases of exposed area. They are readily obtained from the previous columns by making allowance for the horse-power necessary to haul that part of every ton, total weight, which must go into motive power, machinery and fuel. Columns 54 to 62 inclusive, *show the ratios between horse-power required by the two agents for hauling a ton of load (freight and freight car) at the different speeds, efficiencies and area relations.*

It is plain that if we can now obtain the ratio of cost per horse-power, as given by the two agents, in the corresponding cases, we can easily determine the speeds at which the one or the other agent becomes the most economical.

Let us first obtain the cost in electric propulsion.

For this, form table II., showing the elements in the *cost* of one horse-power in stations of various capacity—from 100 to 3,000 horse-power. Engineers and dynamo-men are assumed to re-

TABLE II.

ELEMENTS OF THE COST OF ONE H. P. HOUR, ELECTRIC, IN CENTS.

| Capacity.... ..... | 100 | 300 | 500 | 800 | 1,000 | 1,500 | 2,000 | 3,000 | 4,000 | 5,000 | 6,000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Engineer..... | 0.4 | 0.13 | 0.08 | 0.05 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| Fireman ... ..... | 0.3 | 0.10 | 0.06 | 0.037 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Dynamo man..... | 0.4 | 0.13 | 0.08 | 0.05 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| Helper.. ..... | 0.25 | 0.08 | 0.05 | 0.031 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 |
| Superintendence ... | 0.30 | 0.10 | 0.06 | 0.037 | 0.03 | 0.02 | 0.015 | 0.001 | 0.001 | 0.001 | 0.001 |
| Coal ..... | 0.475 | 0.475 | 0.475 | 0.475 | 0.475 | 0.475 | 0.475 | 0.475 | 0.475 | 0.475 | 0.475 |
| Oil, waste and water. | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| Interest and depreciation steam plant.... | 0.057 | 0.051 | 0.044 | 0.033 | 0.028 | 0.022 | 0.022 | 0.022 | 0.022 | 0.022 | 0.022 |
| Ditto electric plant.. | 0.057 | 0.051 | 0.044 | 0.033 | 0.028 | 0.022 | 0.022 | 0.022 | 0.022 | 0.022 | 0.022 |
| Ditto building.... .. | 0.028 | 0.026 | 0.022 | 0.168 | 0.014 | 0.011 | 0.011 | 0.011 | 0.011 | 0.011 | 0.011 |

ceive 40 cents per hour, and to superintend a maximum of 1,000 horse-power. This would produce, in some cases, fractional engineers, as for a 1,500 horse-power plant, but such complication has been avoided by assuming a constant value per unit of power, in the pay-roll element in plants exceeding 1,000 horse-power. Firemen and helpers are taken at 30 and 25 cents per hour, respectively. Superintendence, at 30 cents per hour, is apparently low, but is equivalent to 60 cents for daylight hours, since the plant is able to run 24 hours with the same general superintendence as for 12 hours. It is further supposed that the total of this item will not require increase until the capacity reaches 3,000 horse-power, beyond which it remains constant per unit of power. As no other element of cost is supposed to vary be-

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yond this point, the table shows here a minimum total cost per unit, and a constant cost beyond it.

Coal is assumed to cost $3.00 per ton, and to be consumed at the rate of 3.2 pounds per electric horse-power hour in the dynamo. A very slight error is made in taking the rate of consumption as constant while changing the capacity of the engines.

Cost of steam plant is taken to vary from $50 per horse-power in a small plant to $20 in a plant of 1,500 horse-power. This latter figure may seem too low to some, but I have recently seen the figures for an 800 horse-power plant, in a neighboring Massachusetts city, which cost, in place, at the rate of $22 per horse-power.

Dynamo plant is taken to vary from $50 to $20 per horse-power in going from 100 to 1,500 horse-power. I know that machinery of good design can be manufactured for these prices.

The cost of buildings is taken to vary from $25 to $10 per horse-power. This is the most indefinite item. Interest, maintenance and taxes are roundly assumed at 10 per cent. per annum on the whole plant.

With Table II. as a basis, Table III. has been calculated, giv-

TABLE III.

TOTAL COST OF ONE H. P. HOUR.

| Output in per cent. of capacity while working. | Hours of work per day. | Capacity of Station. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 100 | 300 | 500 | 800 | 1000 | 1500 | 2000 | 3000 |
| 100 | 24 | 2.42 | 1.29 | 1.06 | 0.9045 | 0.860 | 0.835 | 0.825 | 0.816 |
| " " | 18 | 2.52 | 1.39 | 1.115 | 0.933 | 0.883 | 0.855 | 0.849 | 0.829 |
| " " | 12 | 2.85 | 1.52 | 1.225 | 1.028 | 0.955 | 0.95 | 0.895 | 0.867 |
| 90 | 24 | 2.62 | 1.36 | 1.12 | 0.947 | 0.93 | 0.86 | 0.85 | 0.83 |
| " " | 18 | 2.77 | 1.45 | 1.17 | 0.98 | 0.91 | 0.88 | 0.87 | 0.853 |
| " " | 12 | 3.10 | 1.61 | 1.29 | 1.06 | 0.99 | 0.94 | 0.925 | 0.89 |
| 80 | 24 | 2.87 | 1.45 | 1.18 | 0.987 | 0.92 | 0.91 | 0.88 | 0.86 |
| " " | 18 | 3.06 | 1.55 | 1.23 | 1.03 | 0.98 | 0.936 | 0.926 | 0.90 |
| " " | 12 | 3.42 | 1.73 | 1.37 | 1.13 | 1.06 | 1.000 | 0.98 | 0.95 |
| 70 | 24 | 3.19 | 1.57 | 1.26 | 1.04 | 0.96 | 0.925 | 0.91 | 0.89 |
| " " | 18 | 3.42 | 1.68 | 1.32 | 1.09 | 1.01 | 0.952 | 0.94 | 0.91 |
| " " | 12 | 3.82 | 1.90 | 1.48 | 1.19 | 1.09 | 1.02 | 1.01 | 0.97 |
| 60 | 24 | 3.62 | 1.73 | 1.36 | 1.11 | 1.01 | 0.975 | 0.96 | 0.94 |
| " " | 18 | 3.85 | 1.85 | 1.44 | 1.16 | 1.06 | 1.015 | 1.00 | 0.965 |
| " " | 12 | 4.31 | 2.11 | 1.63 | 1.30 | 1.17 | 1.085 | 1.07 | 1.015 |
| 50 | 24 | 4.22 | 1.95 | 1.52 | 1.20 | 1.10 | 1.045 | 1.03 | 1.00 |
| " " | 18 | 4.50 | 2.10 | 1.61 | 1.27 | 1.15 | 1.09 | 1.076 | 1.039 |
| " " | 12 | 5.09 | 2.40 | 1.83 | 1.43 | 1.28 | 1.19 | 1.17 | 1.114 |
| 40 | 24 | 5.11 | 2.28 | 1.73 | 1.35 | 1.21 | 1.15 | 1.13 | 1.10 |
| " " | 18 | 5.47 | 2.48 | 1.88 | 1.44 | 1.33 | 1.25 | 1.23 | 1.17 |
| " " | 12 | 5.20 | 2.62 | 2.17 | 1.64 | 1.50 | 1.38 | 1.35 | 1.28 |
| 30 | 24 | 6.63 | 2.84 | 2.10 | 1.59 | 1.40 | 1.325 | 1.30 | 1.26 |
| " " | 18 | 7.08 | 3.02 | 2.27 | 1.71 | 1.51 | 1.40 | 1.38 | 1.32 |
| " " | 12 | 8.06 | 3.52 | 2.65 | 1.98 | 1.73 | 1.57 | 1.54 | 1.44 |

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ing total cost per horse-power hour in stations of various capacities, working at various percentages of full capacity and for 24, 18 and 12 hours per day, respectively.

A glance at the table shows that in a 100 horse-power plant the cost varies from 2.42 cents for a 24 hour run at full capacity, to 8.06 cents for a 30 per cent. output continued only 12 hours per day.

This extreme case would doubtless be ameliorated by dropping the superintendence and combining engineer and fireman—though to this the unions might object. This capacity is smaller than need be considered for any steam-line service.

The minimum cost given by the table is 0.816 cent; this for a 3,000 horse-power plant, working full capacity 24 hours per day.

The next element of cost—that of the conductors for the current—is obtained from Table IV. showing investment in dollars for the copper required to transmit one horse-power a distance of one mile, at varying initial and final pressures. The constants for this table were thus obtained: Taking a well-known line wire, I find that from No. 4 to No. 000 B. W. G., the average weight ratio of insulated to bare wire, per unit of length, equals 0.844. When bare copper sells at 15 cents, this insulated wire sells at 20 cents = 22.5 cents on the copper alone, when insulated. If, therefore, we take copper at 25 cents per pound we provide for a very good insulation. The cost of one mil-mile is thus found to be $0.004. Combining this with the familiar formula.

$$C\,M = \frac{16{,}600 \times \text{h. p. transmitted} \times \text{distance in feet.}}{\text{E. M. F. at motor} \times \text{volts lost on line} \times \text{motor efficiency,}}$$

the tabulated values have been determined from the resulting formula:

$$\text{Cost} = \frac{760{,}320}{(E - V)\,V}, \qquad (1)$$

in which $E$ = E. M. F. at station, $V$ = volts lost on line; motor efficiency is taken at 90 per cent. and distance at 5,280 feet. The tabular figures give the investment. To reduce to actual cost per horse-power hour, rate of interest and depreciation, and ratio between power transmitted and power possible to be transmitted must be had. For one year the possible horse-power hours = 365 × 24. Take annual interest and depreciation at 1-16 the investment and ratio of actual to possible power trans-

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## TABLE IV.—FOR DOUBLE METALLIC CIRCUITS.

COPPER INVESTMENT, IN DOLLARS, FOR TRANSMITTING ONE H. P. ONE MILE.

Motor efficiency = 90 per cent.

*Initial E. M. F.*

| Drop on line, volts. | 500 | 1,000 | 1,500 | 2,000 | 2,500 | 3,000 | 3,500 | 4,000 | 4,500 | 5,000 | 5,500 | 6,000 | 7,000 | 8,000 | 9,000 | 10,000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 19.00 | 8.44 | 5.42 | 4.00 | 3.20 | 2.60 | 2.20 | 1.80 | 1.60 | 1.44 | 1.40 | 1.28 | 1.10 | 0.98 | 0.84 | 0.76 |
| 200 | 13.66 | 4.80 | 3.42 | 2.12 | 1.64 | 1.34 | 1.14 | 1.00 | 0.88 | 0.78 | 0.70 | 0.64 | 0.56 | 0.48 | 0.42 | 0.38 |
| 300 | 19.00 | 3.60 | 2.12 | 1.50 | 1.20 | 0.94 | 0.80 | 0.68 | 0.60 | 0.54 | 0.48 | 0.44 | 0.36 | 0.32 | 0.28 | 0.26 |
| 400 | | 3.20 | 1.72 | 1.20 | 0.92 | 0.72 | 0.60 | 0.52 | 0.44 | 0.40 | 0.34 | 0.32 | 0.28 | 0.24 | 0.22 | 0.20 |
| 500 | | 3.00 | 1.50 | 1.00 | 0.76 | 0.60 | 0.50 | 0.40 | 0.36 | 0.34 | 0.30 | 0.28 | 0.22 | 0.20 | 0.18 | 0.16 |
| 600 | | 3.20 | 1.40 | 0.92 | 0.66 | 0.54 | 0.42 | 0.34 | 0.32 | 0.28 | 0.26 | 0.22 | 0.20 | 0.16 | 0.15 | 0.14 |
| 700 | | 3.60 | 1.34 | 0.82 | 0.60 | 0.46 | 0.38 | 0.32 | 0.28 | 0.24 | 0.22 | 0.20 | 0.16 | 0.14 | 0.12 | 0.10 |
| 800 | | 4.80 | 1.34 | 0.80 | 0.56 | 0.42 | 0.34 | 0.30 | 0.26 | 0.22 | 0.20 | 0.18 | 0.14 | 0.14 | 0.10 | 0.10 |
| 900 | | 8.44 | 1.40 | 0.76 | 0.54 | 0.40 | 0.32 | 0.28 | 0.22 | 0.20 | 0.18 | 0.16 | 0.12 | 0.12 | 0.10 | 0.08 |
| 1,000 | | | 1.50 | 0.76 | 0.50 | 0.36 | 0.30 | 0.24 | 0.20 | 0.18 | 0.16 | 0.15 | 0.12 | 0.10 | 0.08 | 0.08 |
| 1,200 | | | 2.12 | 0.80 | 0.48 | 0.34 | 0.28 | 0.22 | 0.18 | 0.16 | 0.14 | 0.12 | 0.10 | 0.08 | 0.08 | 0.07 |
| 1,400 | | | 5.42 | 0.90 | 0.48 | 0.33 | 0.26 | 0.20 | 0.18 | 0.14 | 0.12 | 0.10 | 0.08 | 0.08 | 0.06 | 0.06 |
| 1,600 | | | | 1.12 | 0.52 | 0.34 | 0.24 | 0.20 | 0.16 | 0.14 | 0.12 | 0.10 | 0.08 | 0.06 | 0.06 | 0.056 |
| 1,800 | | | | 2.12 | 0.60 | 0.34 | 0.24 | 0.18 | 0.16 | 0.12 | 0.10 | 0.09 | 0.08 | 0.06 | 0.06 | 0.05 |
| 2,000 | | | | | 0.76 | 0.36 | 0.24 | 0.18 | 0.15 | 0.12 | 0.10 | 0.08 | 0.06 | 0.06 | 0.054 | 0.046 |
| 2,400 | | | | | 3.20 | 0.52 | 0.28 | 0.20 | 0.14 | 0.12 | 0.10 | 0.08 | 0.06 | 0.05 | 0.048 | 0.04 |
| 2,800 | | | | | | 1.34 | 0.38 | 0.22 | 0.16 | 0.12 | 0.09 | 0.08 | 0.06 | 0.05 | 0.04 | 0.038 |
| 3,200 | | | | | | | 0.78 | 0.30 | 0.18 | 0.12 | 0.10 | 0.08 | 0.06 | 0.05 | 0.04 | 0.034 |
| 3,600 | | | | | | | | 0.54 | 0.22 | 0.14 | 0.10 | 0.08 | 0.06 | 0.05 | 0.04 | 0.032 |
| 4,000 | | | | | | | | | 0.36 | 0.18 | 0.12 | 0.08 | 0.06 | 0.046 | 0.038 | 0.032 |
| 4,500 | | | | | | | | | | 0.60 | 0.16 | 0.10 | 0.06 | 0.04 | 0.036 | 0.030 |
| 5,000 | | | | | | | | | | | 0.30 | 0.15 | 0.06 | 0.04 | 0.038 | 0.030 |
| 6,000 | | | | | | | | | | | | | 0.12 | 0.06 | 0.04 | 0.032 |
| 7,000 | | | | | | | | | | | | | | 0.10 | 0.054 | 0.036 |
| 8,000 | | | | | | | | | | | | | | | 0.08 | 0.046 |
| 9,000 | | | | | | | | | | | | | | | | 0.008 |

In using the table it will be convenient to draw curves of equal cost. They will be, roughly, arcs of circles convex toward the left.

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mitted per annum at 1.0, 0.8, 0.6, 0.4, 0.2, 0.1, 0.05, then the divisor of the tabular number becomes 140,160, 112,128, 84,096, 52,064, 28,032, 14,026 and 7,008 respectively.

It remains to obtain values for the distance of transmission.

Let $n$ = number of miles of line supplied from one station.

$h$ = horse-power required for unit locomotive.

$K$ = maximum number locomotives per mile at any time.

$n\,h\,K$ = total power to be transmitted at time of $K$.

$A$ = percentage of dynamo power lost on line.

$\frac{n\,h\,K}{100-A}$ = maximum power to be generated.

$\frac{n\,h\,K}{100-A} \times \frac{A}{100}$ = " " lost on line.

$b$ = cost in cents of generating one horse-power hour in station.

$r$ = ratio of average power required to maximum power required.

$L$ = interest and depreciation on supporting structure.

This last may be omitted from the calculation, determining division of line into section, since it remains the same, whatever that division may be. Omitting this, the expression for cost of transmission becomes:

$$\text{Cost} = \frac{760{,}320\,n^3\,h\,K\,r}{(E-V)\,V \times 140{,}160} + \frac{b\,n\,h\,K\,A}{r\,(100-A)\,100}$$

$$= \frac{5.42\,n^3\,h\,K\,r}{(E-V)\,V} + \frac{b\,n\,h\,K\,A}{r\,(100-A)\,100} \qquad (2)$$

Supposing that the time schedule of trains, horse-power required per train, and efficiency of motors be known, and that the initial E. M. F. be in all cases taken as high as the state of the art permits, the only variables remaining in this expression are $n$, $b$ and $A$. This latter, the value for the drop on the line, will generally be determined by conditions other than those of strictest economy, as shown by getting a minimum value for cost of transmission. We must have a reasonably uniform E. M. F all along the line, in order that the motors may work satisfactorily. It will not be wide of the mark to assume 10 per cent. as a limiting variation of line potential. This is the figure generally assumed in calculating wire for street railways.

The cost of one h. p. hour $b$ must vary with the capacity and conditions of working of the station; hence it is a function of

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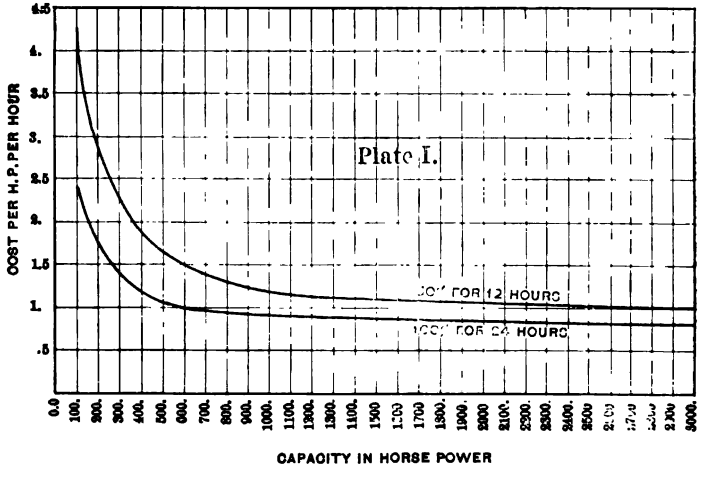
$n$—*i. e.*, length of unit section, of $A$, and of that inexpressible variable— the conditions of the service. This stands in the way of obtaining any perfectly general definite expression for $n$, which, but for this, would result from placing the first differential coefficient of $C$, with respect to $n$, equal to zero, and solving to find the value of $n$, giving a minimum value for $C$. If trains be run at very short intervals, increase of $n$ would be followed by proportional increase in capacity of station; but, as above shown, this need not go beyond 3,000 h. p. unless the service be so heavy as to require practically contiguous stations of that capacity. If we suppose a case of this short-interval service, so short that a change in $n$, will not be followed by any change at the station in the relation between maximum capacity and aver-




age output, or in the number of working hours, but only in the normal capacity, the relation between $b$ and $n$ for two cases of average output and working hours is shown by Fig. 1. The equation of the 50 per cent. curve from 200 to 1,000 h. p. seems to be very nearly

$$b = \frac{n^2 - 98n + 1{,}000}{12\,(n - 100)}.$$

If the trains be run at very long intervals, we may require no greater station capacity for 20 than for 10-mile sections; but the relation of output to normal capacity will vary, and possibly the number of hours during which the working force would require to be kept on pay.

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Taking the case of a change on average output only, for a 1,000 h. p. station, we have the curves in Fig. 2, for 24, 18 and 12 hours' work. The equations are nearly of the same form, and are approximately the equations of arcs of circles referred to an origin outside the circle. But each would contain different constants, and would vary more or less from the exact formula for the circle.

If, in the application to a particular case, the algebraic expression for $b$, above given, or any other resulting from any of the possible progressions through Table III., be substituted in Eq. 2, we may, by differentiation, solve that particular case for the most economical value of $n$. If the relation between $b$ and $n$ cannot be algebraically expressed, then the proper value for $n$ may be determined by a few trial values, the corresponding values of $b$ being taken from the table.

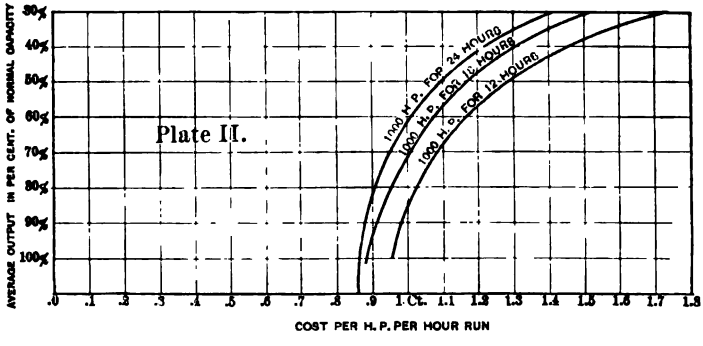
Plate II.
1000 H.P. FOR 24 HOURS
1000 H.P. FOR 18 HOURS
1000 H.P. FOR 12 HOURS
AVERAGE OUTPUT IN PER CENT. OF NORMAL CAPACITY
COST PER H.P. PER HOUR RUN

For the present purposes of comparison, we will assume a case not more favorable than might often be met on busy steam lines, *i. e.*, a station of 2,000 h. p. normal capacity, working 18 hours per day at 40 per cent. of its normal output, the cost per horse-power being 1.25 cents.

To obtain the cost of the line, we will assume that the average distance of transmission is five miles. This would correspond to one station for every twenty miles of road. We will also assume 5,000 volts initial E. M. F. and 10 per cent. drop. From Table IV. the copper investment is found to be 34 cents for one mile. Then for five miles the investment equals $8.50. Making assumptions as to service corresponding to those for the station, we have cost of one horse-power equaling $8.50 ÷ 20,000 = 0.042 cent.

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The structure for carrying the conductors may be built for $2,000 per mile. Interest and depreciation would then become $200 per annum. This total is almost wholly independent of the power transmitted, hence the cost per unit of power will vary directly with the number of units transmitted. Assuming a constant distribution of one 500 h. p. train for every 20 miles of line, we have the cost of this item for 1 h. p. hour:

$$20{,}000 \div 365 \times 24 \times 25 = 0.09 \text{ cent.}$$

Reaching the locomotive, we must add, supposing an average output of 500 h. p., 0.08 and 0.06 cent respectively for driver and his assistant. The latter is necessary only as a substitute for his principal in case of emergency, but as such he would doubtless always be placed on trains of considerable value.

Repair on electric locomotives is not as yet well defined. That the repair bill must be far less than in the case of steam locomotives follows almost necessarily from the great reduction in the number of parts, especially of moving parts.

From Mr. Arthur Wellington's very valuable work on railways, I take the figures showing percentage distribution of locomotive repairs by parts.

Boiler, 20 per cent.; running gear, 20 per cent.; machinery, 30 per cent.; lagging and painting, 12 per cent.; smoke box, etc., 5 per cent.; tender (running gear, 10 per cent.; body and tank, 3 per cent.) 13 per cent.; total, 100 per cent.

Of these items we may at once, and with certainty, strike out boiler, smoke-box, etc., and tender, thus dropping 38 per cent. of the total. Having no boiler to carry, the running gear will be less in quantity.

The wear will be less, due to the use of rotary instead of reciprocating effort. It will then be fair to reduce this item by half, making another saving of 10 per cent. So in the machinery item, there can be no question that with the rapid advance toward slow-speed motors, reducing gearing, and sounder insulation methods, the great advantage of having only *one moving part* in the motor itself must operate to very largely reduce the repair figure, probably to half its value in a steam locomotive, leaving it at 15 per cent. In lagging and painting, the omission of boiler and other parts must again effect a reduction, say to 6 per cent. The total reduction thus plainly indicated must be then very nearly 70 per cent.

The actual cost of repairs to-day on steam locomotives is, on

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the P. R. R. nearly 0.75 per h. p. hour, as will later appear. Reducing as above, this figure becomes 0.22 cent for electric traction. This refers to engines of considerable power; say from 400 to 1,000 h. p. capacity. The figure for both steam and electric motors would go up for smaller powers.

The interest charge results from considering the cost of an electric locomotive as $50 per h. p. and the duty as six hours per day full capacity. The average duty of steam locomotives is only about three hours. The higher figure results from a smaller number of repairs necessary, due to greater simplicity of parts, Then

$$\text{Interest for h. p. hour} = \frac{50.00 \times 0.05}{365 \times 6} = 0.11 \text{ cent.}$$

Before summarizing we must know something of the efficiency of the system. If the locomotive be of 90 per cent., or 80 per cent., or 60 per cent. efficiency, we must generate, respectively. 1.25, 1.4, and 1.85 h. p. hour in the station for every h. p hour actually delivered to drivers, line loss being supposed constant at 10 per cent.) We should then have in the station 1.56, 1.75 and 2.30 cents, respectively.

Then, for total:

| Station | 1.56 | 1.75 | 2.30 |
|---|---|---|---|
| Conductor system | 0.042 | 0.04 | 0.04 |
| Structure for same | 0.09 | 0.09 | 0.09 |
| Wages | 0.14 | 0.14 | 0.14 |
| Repairs | 0.22 | 0.22 | 0.22 |
| Interest | 0.11 | 0.11 | 0.11 |
| Total | 2.16 | 2.35 | 2.90 |

Of the whole amount, it is to be noted that the station item is three-fourths. Taking the most favorable case shown by the table,—3,000 h. p. capacity, working for 24 hours at 100 per cent. of capacity—those figures become 1.5, 1.62 and 2.00 cents nearly, the reductions in the other items being still a little indefinite, without making another series of independent assumptions.

The cost of one h. p. hour, excited by steam locomotives, is to be obtained only by some circumlocution, the reports of cost being based on train-mile. As quoted by Wellington, the coal consumed per passenger train-mile on the Pennsylvania Railroad is very closely 50 pounds, and an average performance will show 5 pounds coal per h. p. hour, while *under way. This shows that one train-mile equals* 10 *h. p. hours.* The coal consumption for a freight train-mile is much higher, but the divisor would also be

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higher, on account of the greater number of stops, or at least of backing and switching, and greater delays while on a trip, thus increasing waste of coal.

Again, the Pennsylvania Railroad reports show cost of fuel per train-mile of 5 cents. The cost of coal to that company, as nearly as I can learn, is about $1.50 per ton. Hence it would appear that 66 pounds per train-mile are consumed. As the terminal losses of fuel and delay (getting up steam and drawing fires, etc.) are known to be in the neighborhood of 25 per cent. of the total consumption, we have 6.6 (pounds) as the divisor, and the same ratio again appears.

The cost of one train-mile—as to motor power alone—is given by the Pennsylvania Railroad as 22 cents. And this is practically equal to the average for the United States. The itemized statement is very carefully made up, and seems to cover everything except interest on the engine investment.

Knowing the annual mileage per locomotive to be about 20,000 and the cost to be $10,000, interest charge per train-mile (not quite, but nearly, equivalent to engine mile) becomes 2.7 cents. Total cost becomes 24.7 cents, or 2.47 cents per h. p. hour.

We may safely use this figure in the comparison to be made, since any positive error in the calculation of coal per h. p. hour, or negative error in h. p. hours per train-mile, will be offset by the difference in cost of coal per ton to the P. R. R. as compared with the value assumed in Table III.

At $3, instead of $1.50, the fuel item would be 10 cents and the total motive power 29.5 cents. Leaving the statistics of actual cost, we may reach, by the method of Table III., nearly the same figure, considering the locomotive as a 1,000 h. p. steam plant, of low first cost, burning 6 lbs. of coal per h. p. hour, and working at one-third capacity for about three hours per day. The result thus reached is about 10 per cent. higher, but the 2.47 cents seem most reliable.

These values multiplied into the corresponding values in the last nine columns of Table I., give the following values of:

$$\frac{\text{Power units, steam}}{\text{Power units, electric}} \times \frac{\text{cost per unit, steam.}}{\text{cost per unit, electric.}}$$

This value, Table V., being greater than unity indicates greater economy by electricity than by steam, and vice versa.

A glance at the table shows the dominating necessity of in-

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TABLE V.
*Ratios of cost of motive power.*

| Efficiency of electric engine. | 10 per cent. | | | 20 per cent. | | | 40 per cent. | | |
|---|---|---|---|---|---|---|---|---|---|
| Tonnage and area relation. | 2 & 3 | 2 & 5 | 2 & 8 | 2 & 3 | 2 & 5 | 2 & 8 | 2 & 3 | 2 & 5 | 2 & 8 |
| Speed. | | | | | | | | | |
| 20 | 1.15 | 1.16 | 1.16 | 0.92 | 0.85 | 0.85 | 0.56 | 0.56 | 0.55 |
| 40 | 1.19 | 1.19 | 1.17 | 0.95 | 0.95 | 0.95 | 0.57 | 0 57 | 0.56 |
| 60 | 1.25 | 1.24 | 1.19 | 1.00 | 1.00 | 0.95 | 0.58 | 0 58 | 0 56 |
| 80 | 1.33 | 1.32 | 1.22 | 1.07 | 1.03 | 0.94 | 0.59 | 0.59 | 0.57 |
| 100 | 1.58 | 1.42 | 1.32 | 1.23 | 1.20 | 1.05 | 0.66 | 0.65 | 0.59 |
| 120 | 2.57 | 1.94 | 1.47 | 1.66 | 1.49 | 1.13 | 0.80 | 0.78 | 0.64 |
| 140 | 10.03 | 3.82 | 1.87 | 7.35 | 2.83 | 1.46 | 2.72 | 1.36 | 0.72 |

creasing the efficiency of the mechanism delivering energy from the electric line to the vehicle. We cannot count upon a higher efficiency than 90 per cent. for the motor. Hence, save in the case of putting the armature directly on the axle, we cannot hope to reduce the total loss to less than 20 per cent.—a case permitting one set (*i. e.*, two gears) of spur gearing between armature and axle. As the ordinary relation between tonnage and resisting area will lie between the second and third columns of each effi ciency table, it appears that with a 20 per cent. loss, electricity becomes cheaper than steam at about 70 miles per hour.

In the case of 40 per cent. loss our new agent betters the old only at 140 miles per hour. And yet this loss—40 per cent.—is about the best we do with our present systems of electric propulsion. This appears from the following tabulation of results obtained by me on the Brooklyn & Jamaica Electric Railway, Table VI.

Considering the very short life of the art, these results are excellent. Indeed, excellence is shown in the mere fact of success in competing with horses under conditions very trying for any mechanism not made of india-rubber or whit-leather. How great that success has been I need not here proclaim. But the steam locomotive is a foeman more worthy of our steel, or rather of our annealed soft iron, and 99 per cent. copper.

Consideration of all that precedes leads to the following general conclusions:

1. A slow-speed armature placed on the car axle would place the electric motor in the lead at all service speeds.

2. For speeds above 70 miles per hour an electric motor of 90 per cent. efficiency, working through gearing of 90 per cent.

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efficiency would prove more economical than the steam locomotive—save in cases of very infrequent service on very long lines.

3. On lines for heavy traffic, steam would be more economical than electricity if motor and gearing have a combined efficiency as low as 60 per cent., up to 100 miles per hour.

4. At speeds of 100 miles per hour and upward, neither steam at 90 per cent. nor electric apparatus at 60 per cent. efficiency is commercially practicable.

5. Inasmuch as the saving of coal in stationary, as compared with locomotive engines, is one of the chief causes of the greater economy of electric propulsion, at any speed, this advantage will increase with that difference and also with the price of coal.

6. Any cause other than inefficiency of motor which increases the power required to haul a ton of freight, increases the advantages of electricity, since it enlarges the value of the coal difference and the dead-weight difference.

Thus, bad roadways and large areas exposed to atmospheric resistance, as in street railway work, lower the speed at which electric motors of any efficiency become cheaper than steam.

7. In descending to small locomotive units, the electric motor loses less, relatively, of its advantage—another reason for success on street lines.

8. Multiplying the number of motors should be, as far as possible, avoided.

9. In special cases cleanliness and compactness of electric machinery may be of great value; in case of very frequent stops, the possibility of returning to the line the energy now wasted in brakes may be of considerable value. This, however, can be obtained only by sacrifice in the matter of dead-weight, as normal working is implied to be at comparatively low magnetization. Loss due to low efficiency in starting can scarcely be avoided either in steam or electric engines.

10. Other minor pros and cons may be enumerated, but I believe that in considering the general economic results of the two systems we reach more definite conclusions.

While only one condition of station working has been taken for final comparison, that case is an average one, and comparative results would be but slightly affected by ordinary varations Extreme cases may be readily determined from the tables and formulæ presented.

11. Some difference of opinion as to the proper values for the

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various constants are to be expected, but I believe these differences, taken all along the line, would nearly balance between positives and negatives, leaving the general results and the method unchanged.

Whether these conclusions be accepted or not, I believe the tables and formulæ here presented will be found valuable.

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## Discussion.

The President:—I am sure we have all been very much gratified in listening to this extremely interesting paper upon a question that is certainly a live issue, if there is a live issue at the present day. We should be glad to hear any remarks upon it. The paper is now before you for discussion.

Dr. Louis Bell:—I wish to state one point in addition to what Mr. Crosby has mentioned in his very exhaustive paper, and that is that the electrical difficulties with which we have to contend in street car work, which have made it so difficult for electricians to get good efficiencies and low repairs—nearly all disappear when we come to these high speeds, due to the fact that we can put the motor directly on the axle, doing away with the gearing, which, as you say, involves a loss of 40 per cent. in efficiency. Furthermore, with the powers required, that is from 400 to 1,000 horse-power, there is no sort of difficulty in building the motor of a higher efficiency, and at the same time putting it directly on the axle, the speed required to drive an express train from 40 to 60 miles per hour, being in a general way from 500 to 550 turns a minute, which for a motor of the size involved is not a necessarily low speed. A 400 horse-power motor would naturally be made to run somewhere near 500 revolutions—not much in excess of that—so that there arises no difficulty in placing the motor directly on the axle, a condition which can at present be fulfilled, if at all, only with immense difficulty in street car service. The electrical difficulties, therefore, very largely disappear for the reason that the motor required for express service upon railroads would be so large that it could be made to run at as low a speed as is required for express service and at the same time have a high efficiency. I do not think that any man who is used to the designing of large electrical machinery would hesitate to design a four pole machine to reach 500 revolutions and develop 400 horse-power at an efficiency of 85 per cent. which would give electricity an equal chance with steam. Furthermore at these speeds with large motors they will not be placed under the car in the dirt and dust and wet, but will be placed where they can be protected, so that there is no reason apparent on the face of it why a 300 or 400 or 500 horse-power motor should not be operated with the same efficiency, with the same freedom from repairs, with the same ease as we now operate large dynamos in a central station.

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MR. F. L. POPE:—In my opinion the high-speed locomotive of the future will not be managed by an intelligent man who goes with it, but will be handled from the ground by men placed at short intervals along the line to guard against obstructions of all kinds, and who will be able simply by taking a pair of nippers and cutting a small wire running along the track to bring any train to a stand on any section in a few moments automatically, if they discover anything the matter with the track or any obstruction in the way. It is rather difficult to imagine what an engine-man, going at that rate of speed, would be able to do if he did see anything in the way, because he would get to it almost before he saw it.

MR. CROSBY:—I might say the presence of a man on a locomotive is of less value for taking care of accidents due to a possible obstruction on the track than for handling the locomotive at starts and stops. I am aware of no way of making an electric engine start and stop properly without some form of wasting energy, either an external resistance or some compensation of internal resistance amounting to practically the same thing, and somebody has to exercise intelligence in doing that. It can be done, and I have done it from the station. I have sent a car at a high rate of speed without any one on it, because the track was not a fit one to travel on, and we managed it very well with nothing but a water barrel as a rheostat. But probably there is no reason why a man should not sit on the locomotive and operate some electrical controlling device. As for obstructions they will have to take care of themselves, or the track will have to be well fenced in. I see no way of ameliorating that trouble except by keeping the tracks clear.

PROF. THOMSON:—I would like to add one word in regard to keeping the track clear. It is a question, in my mind, whether a locomotive of that kind would not keep the track clear itself. You have all heard of the experiment of shooting a candle through a board. I have fired wax bullets through a board with an air gun. The wax bullet was found imbedded in the board at quite a depth and in perfect shape; so we may consider perhaps that in getting the locomotive in the proper shape at the end so as to get rid of all obstacles it will get along very well. (Laughter.)

MR. JOSEPH A. MILLER:—I see that the subject of this paper is limitation of steam and electric transportation. Now limitation in that sense is similar to a limitation of how far you can see. It is a limitation as far as we can see now. Now, I have lived quite a length of time. I have seen the development of steam railroads, the introduction of gas, of electricity, etc., and what were limitations five or ten years ago are not limitations now.

What must we do to increase our speed? Well, the first thing we must do is to reduce our dead weight so as to have a larger paying weight.

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How can we do it?

The locomotive's enormous weight is a destruction to the tracks; again, the increase in the length of cars demands greater weight and greater strength on account of the greater length they have to support. Do away with the locomotive first. It is an enormous expense, an enormous weight, etc. The next thing is to support your cars the whole length so that you do not have to bridge-truss them.

How?

Knock out these running gears and put them on skids.

MR. CROSBY:—I can only be gratified at the slight misunderstanding, since it has brought out such an entertaining dissertation on the matter. I mean limitations as compared each with the other. I do not mean to say that I have fixed a limit.

PROF. W. L. HOOPER:—I was much interested in what Mr. Crosby had to say in regard to resistances at high velocity. Some time ago I looked into the subject somewhat, and the ordinary values for the co-efficient seemed too high. The velocities, however, were very high. I obtained the result of careful tests made on the projectiles of the new eight-inch rifles for the United States Navy and at the various velocities given, the resistances were roughly proportioned to the square of the velocity, but the co-efficient was much smaller than is commonly used in engineering. But it may perhaps be interesting to know that velocity at a little less than 2,000 feet per second, the horse-power expended in overcoming the air in the case of a projectile weighing 300 pounds was nearly 3,000 horse-power. That is a velocity of 23 or 24 miles a minute—1,400 miles, say, an hour.

MR. CROSBY:—Referring to the matter of atmospheric resistance I can only repeat a good deal of what appears in the paper I have written on the subject, and which is now in print. The law of variation of velocity is a changing law and at times the variation is as high as with the sixth power of the velocity. The high values attained in ordnance gives us a succession of changing exponents for V. Starting with $V^2$ at the lowest ordnance velocities, which, however, are very much higher than anything we call engineering velocities, that exponent increases to the sixth power, and that very high rate of change holds over a short range of velocity from about 1,300 to 1,700 feet per second, perhaps. Then there is a gradual diminution in the exponent, and at the highest attained velocities in ordnance experiments the square again is found to be the exponent of V. But the demonstration I made, carried the velocities nearly to the lower limit of ordnance velocities above the present range of engineering velocities, and in that range, the variation, so far as anything can be detected in quite an extended series of experiments, is a rectilinear variation, but it is because the exponent is found to be so variable a one that I feel it rather strengthens

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the position I have taken. Save for the authority of absolute experiment over any range of velocities there is no proper guide for determining the pressure with respect to velocity.

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# PRACTICAL ASPECTS OF THE ALTERNATING CURRENT THEORY.

DISCUSSION OF DR. M. I. PUPIN'S PAPER AT THE GENERAL MEETING, BOSTON, MAY 21, 1890.

(*See page* 204 *ante.*)

THE PRESIDENT:—We would be glad to hear any remarks now upon this very interesting paper.

MR. CROSBY:—I would like to ask whether Dr. Pupin finds that it is really a simple matter to design an alternating motor as compared with the work of designing a continuous current machine. While the general theory may be expressed with almost equal simplicity, will not the introduction of those mathematics, the value of self and mutual induction, make it a more difficult matter to design an alternating than a continuous current machine?

DR. PUPIN:—Well, not being a practical man and never having designed an alternating current machine or a continuous current machine, I, of course, could not answer that question.

PROF. THOMSON:—I should say that having designed both continuous and alternating machines, I see no particular difficulty in doing either; there are certain things that are left out altogether in the design of alternators which have to be considered in the designing of continuous current machines, as in the commutation. Of coure the simplest forms of expression will not take in all the little attentions that have to be given in that direction. So it is with the alternator we may say that there are some things to be attended to which are not taken in in the simplest forms of expression, but so far as I can see I should say that the problem is not more complex than that of designing a good continuous current machine.

THE PRESIDENT:—I understand that the experiments which are to be taken up in the next paper require the use of the steam engine and that steam is being kept up for us, and I think we had better pass on to the next paper and resume this discussion later. There will be an opportunity for continuing this discussion after the reading of the paper by Mr. Lemp on automatic electric welding machines.

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*A paper read at the General Meeting of the American Institute of Electrical Engineers, Boston, Mass., May 21st, 1890.*

# AUTOMATIC ELECTRIC WELDING MACHINES.

BY HERMANN LEMP, JR.

AMONG the latest achievements in electrotechnics, stands prominently Prof. Thomson's electric welding process. The broad underlying principle has so often been described and exhibited by its able discoverer and others, that to repeat it now would be imposing upon your patience. The evolution of a new process and its reduction to practice for commercial purposes, especially if the leading elements of its working are novel in themselves, must necessarily open a vast field for investigation. Such is the case with electric welding, and with a view of showing the commercial apparatus of to-day, it will be necessary for me to state the electrical and mechanical requirements which led to its construction.

The reason for which machines have been invented has been for the purpose of reproducing faithfully and constantly a set of conditions necessary to obtain a certain result. When the conditions in any case are few and the product simple, generally one design of machine will be sufficient. With an increased number of conditions, however, the complexity of the apparatus increases rapidly and demands, in many cases, a subdivision into different processes to be executed by separate machinery. What constitutes skill in a workman, for instance, is the ability to coordinately reproduce a number of operations or movements; to be, in other words, a perfect machine, or to produce the same result even if other conditions than those previously contemplated should arise.

To secure uniform results in the practice of a difficult operation, there are two ways possible.

1. To employ skilled help for the complex portion of the work alone.

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2. To substitute for the more complex portion of the operation one more readily controlled.

The ordinary welding process requires the greatest skill at the hands of the blacksmith for heating the metals to the proper temperature and at the right spot, while preventing the accumulation of cinder or scale. While skill may be successful with metals of high melting points and low conductivity for heat, easily fusible metals and specially good conductors baffle all attempts as long as an exterior heating source is employed.

The electric welding process has, as you know, not only made it possible that operators not particularly skilled in the art of blacksmithing can produce good substantial welds, but has created an art equally adaptable to all metals and combinations of metals.

The following are all the metals, alloys and combinations so far actually welded with success by the Thomson process;

*Metals.*—Wrought iron, cast copper, antimony, aluminum, manganese, cast iron, lead, cobalt, silver, magnesium, malleable iron, tin, nickel, platinum, wrought copper, zinc, bismuth, gold (pure).

*Alloys.*—Various grades of tool steel, various grades of mild steel, steel castings, chrome steel, musshet steel, stub steel, crescent steel, bessemer steel, cast brass, gun metal, brass composition, fuse metal, type metal, solder metal, german silver, aluminum alloyed with iron, aluminum brass, aluminum bronze, phosphor bronze, silicon bronze, coin silver, various grades of gold.

*Combinations.*—Copper to brass, copper to wrought iron, copper to german silver, copper to gold, copper to silver, brass to wrought iron, brass to cast iron, tin to zinc, tin to brass, brass to german silver, brass to tin, brass to mild steel, wrought iron to cast iron, wrought iron to cast steel, wrought iron to mild steel, wrought iron to tool steel, gold to german silver, gold to silver, gold to platinum, silver to platinum, wrought iron to musshet steel, wrought iron to stub steel, wrought iron to crescent steel, wrought iron to cast brass, wrought iron to german silver, wrought iron to nickel, tin to lead.

But Prof. Thomson was not satisfied with this progress made above ordinary welding, and early recognized the importance of a machine in which all conditions for successful operations are mechanically controlled to produce uniform results, and which would be rapid working and require little or no attendance.

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Such machines now known as automatic welding machines, have proved to be of special importance in connection with easily fusible metals, enabling the successful welding of aluminum, silicon and aluminum bronze, which, even with the electric process, require considerable skill.

Before entering into a detailed description of the automatic welder, a few general data on welding will be in order.

The Thomson process of electric welding can be, and has been, worked by means of continuous or alternating currents; secondary batteries or multipolar machines may be and have been used. There are such conditions as transportability, absence of motive power, situation in continuous distribution district, etc., which may make it advisable to use the continuous current. The alternating currents have so far been the best adapted to be produced economically of large volume at low E. M. F. They are easily and economically controlled, allow of being distributed at high pressure with small conductors and of being reduced to working pressure wherever needed. They have, however, another beneficial effect, which is of importance in all welds of large sections.

It is a well-known fact amongst manufacturers of incandescent lamp filaments of large section that the inner portion in a filament is apt to be overheated. In treating filaments as used in the now commercial series lamp, in a hydro-carbon atmosphere, the writer attempted at one time to produce an extra good quality of carbon by starting with an extremely thin base .004 inch thick and obtaining a filament, 90 to 95 per cent. of which consisted of hard, gray, lustrous carbon. He thought to extend this process to the manufacture of arc light carbons and even produce pencils of about $\frac{1}{4}$ inch diameter. What was his surprise, however, to find that although the lustrous surface presented at times a dense gray structure, the core lost this character after a certain thickness of carbon had been deposited. In fact, a number of concentric layers could be discovered from the innermost graphite to the dense gray semi-crystalline at the outside.

This action can, to my mind, only be attributed to the overheating of the carbon particles in the inside. A similar action takes place in a bar of iron if heated by an electric current. The surface exposed to radiation will be at a lower temperature than the core. It is true that the heating of the metal will increase its resistance and thus tend to equalize the temperature, but not enough in all cases. By the use of alternating currents we gain, however,

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an assistance in the self-induction. The effect of the latter is especially marked and has a tendency to concentrate the heat on the surface.

If there is any place which receives more current than another the effect of the self-induction is emphasized by the fact that the surrounding part is cool and its permeability is greater than the part traversed by the surplus of current. With very large, and especially wide, metal pieces the unevenness of distribution may be remedied by approaching iron masses to create at a given spot a greater self-induction or counter E. M. F., thus diverting the current from that section. Prof. Thomson has early recognized the importance of, and patented, a device to prevent the heating of the metal at a given spot by creating locally increased self-induction or magnetic effects.

In view of this experiment almost daily witnessed by us, it is interesting to note the paper controversy between parties disputing the priority of a device which is to produce exactly the opposite result with, however, the same means and conditions.

Two methods of distribution are in use, the direct and the indirect. In the former, an alternating current dynamo is used, having two windings on the armature, one of which furnishes currents rendered continuous by a commutator to excite the field magnets, and is controlled by switch and rheostat; the other consisting of a single turn of heavy copper cable furnishes the welding currents, which is led through collector and brushes to movable copper clamps suitable to receive and guide the welding specimens during the operation.

In some other forms the field magnet is the movable part, in which case no heavy currents have to be carried through collector and brushes. No direct welders are built at present for currents larger than 4,000 amperes.

The indirect method of distribution is almost exclusively used to-day. It consists in its simplest form of one alternating current dynamo, self or separately excited, and one welder which is a transformer with the necessary clamping and operating appliances. The self-exciting dynamos used are from 1,000 to 20,000 watts output, and may be regulated by means of a reactive coil to give a varying E. M. F. never exceeding 300 volts.

They are substantially built to withstand sudden strains, have self-oiling bearings; the brushes are designed never to be moved

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and are perfectly sparkless, requiring no other attention than cleanliness.

The winding on the transformer being set once for all, variation in the E. M. F. has to be obtained either by varying by hand the initial E. M. F. of the dynamo or by exciting a dynamo to the lowest potential required, it being so compounded as to give with the maximum work the increased E. M. F.; or finally to maintain a constant E. M. F. at the dynamo under all loads and vary the E. M. F. at the transformer by interposing a variable resistance, or preferably a self-inductive resistance. The transformer itself may be built so as to give a different ratio of conversion, either

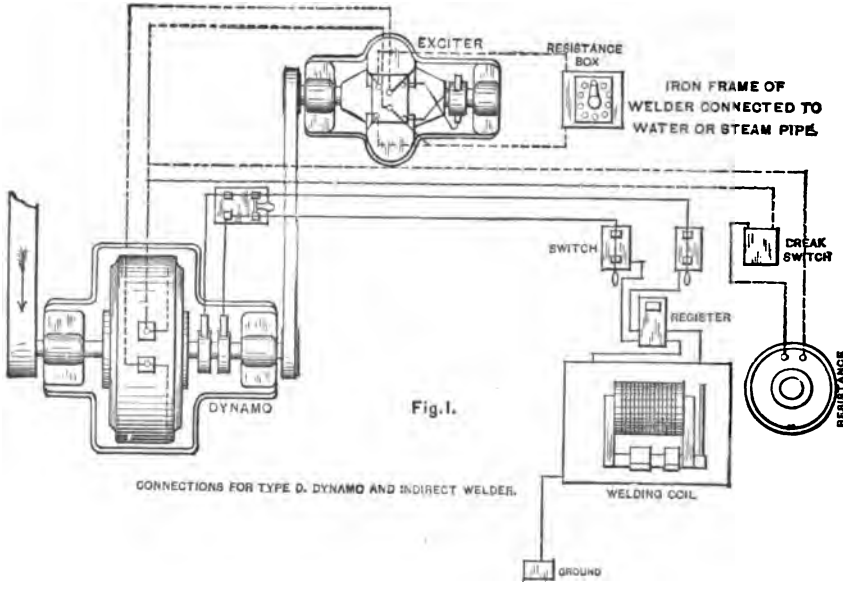


Fig. 1.

CONNECTIONS FOR TYPE D. DYNAMO AND INDIRECT WELDER.

by moving the primary and secondary relatively to each other or by shunting lines of force by means of an iron bridge between primary and secondary, or by altering the number of turns in primary or secondary by a switch.

When a single plant is used, viz., one dynamo and one welder it is the dynamo, generally, which, if separately excited, is regulated by means of a rheostat in the exciter circuit, or by a reactive coil in series with the exciting coil on the armature if self-excited. The diagram, Fig. 1, shows the connections used with a separately excited machine. The only thing different from similar installations is the break switch which is operated by a foot

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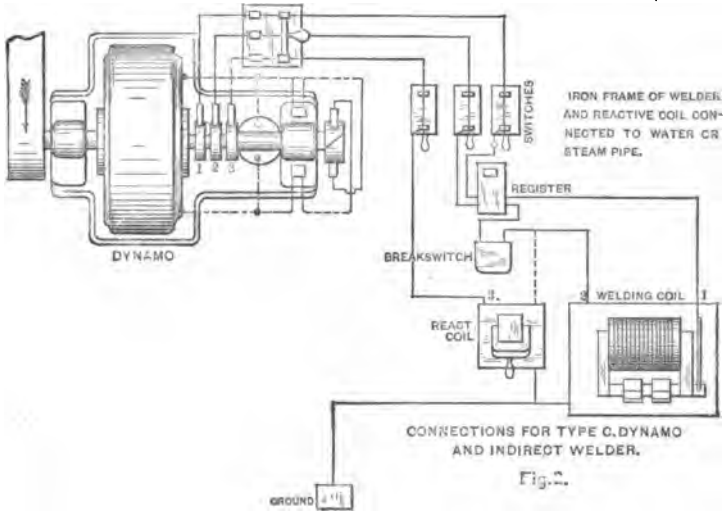
treadle and automatically opens the circuit when the foot pressure is removed.

This prevents any mishaps when operated by uninitiated persons, as all action ceases when one leaves the apparatus. The primary voltage never exceeds 300 volts with 100 alternations, or 50 complete cycles per second. Nothing but the very best insulation is used in the primary wiring. It is deemed necessary to protect users of the apparatus not only against any shocks, but even against the scare of one, and we recommend the permanent grounding of the secondary which in welding apparatus is virtually the table and pressure devices.

Fig. 2 shows the connections used for a self-excited composite




dynamo, which has two windings on the armature, a longer main and shorter exciting coil. Both are wound in the same direction, and currents generated therein pass in multiple, connected through the shunted field magnet; after this through line No. 2, controlled by a break switch, and then split, one returning through reactive coil and line 3, the other through welder and line 1 to their respective windings. The exciting effects of each circuit add themselves. The reactive coil is conveniently placed near the welder. Dynamo is regulated from the minimum to 300 volts and is excited anew for each weld.

For some work which requires to be done at great speed, the second method is resorted to; that is, to keep the field con-

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stantly excited by fixing a variable reactive coil in a given position, just enough to produce about 150 volts, the lowest E. M. F. required. The proportion of the field magnets, the E. M. F. of exciting coil and the resistance of a shunt to the field are such as to produce an overcompounding of 100 per cent. in this case, with the largest current in the primary.

This method of regulation is very neat, as it is absolutely automatic, responds quickly, the field of the dynamo not requiring to "build" every time from residual magnetism alone. We sometimes call it "cubic compounding," as it produces a constant heating effect for variable cross sections and variable lengths as well. With this modification, the wiring of diagram, Fig. 4, is slightly altered, the break switch breaking only the main circuit, leaving the exciting circuit permanently closed.

The methods so far described are only used when a single welding machine is to be operated. It was early recognized that if the process is at all to be used on a commercial basis, the generating of the necessary current at least should be limited to as few machines as possible. It required, in other words, a dynamo giving a nearly constant E. M. F. of sufficient capacity to feed a number of welders while maintaining for each absolute independence.

Since all welding for a long while to come will probably be operated in isolated plants, the dynamo is to be placed in the hands of an engineer, generally not an expert in electrical matters, and has, therefore, to be easily attended and free from all the little faults and kinks which are at present the sole consolation of the dynamo tender. One of its prime requirements is close automatic regulation under all loads.

Constant potential, self-regulating dynamos are manufactured in various sizes and are self-exciting up to 30,000 watts output. Dynamos with larger output are separately excited, but also self-regulating. The methods employed to obtain regulations are novel and will form the subject of another paper at some future date. I would simply state that either constant potential, or a percental increase with load can be obtained and that the regulation will respond even if the load consists of self-inductive translating devices. I lay some stress on the regulation of the dynamo for the reason that the generators are not to be placed in the hands of special attendants as in case of a central station, but have to deliver their currents under constant pressure whatever

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may be the conditions of work they are subjected to; even an automatic regulator would hardly be able to follow the rapid variation of load.

The following conditions influence the perfection of the work and are variable with different material and sizes:

1. Projection of the abutted pieces in the path of the current.
2. E. M. F. of welding current as controlling the strength of current flowing.
3. End pressure applied to force the abutting ends into each other at welding heat.
4. Interruption of current at proper time.

1. The projection of the abutted pieces varies with the diameter. It has been found that for copper, a projection for twice the diameter for each clamp gives the most economical results. With steel and iron, the most economical projection equals the diameter and is one and one-half times the latter for brass.

The projections sensibly affect the energy required and the most economical one depends upon the heat conducting properties and specific resistance of the specimens. Accordingly, highly conducting bodies require longer projections; highly resistant ones, short projections. Conductors of larger and smaller diameters may be welded by giving to each its respective projection. In the same manner wires of different materials may be joined to each other.

It is easily understood that since unequal projections on different sized conductors produce the proper heating of both at their junction, equal projection of equal sized conductors will be required. All other conditions aside, it is important to keep the projection for a given size and material constant.

2. The E. M. F. required depends upon the projection and the resistance of the material to be welded. For large cross sections the specific self-induction plays an important role, and indirectly, the shape of the specimen.

Another factor affecting the E. M. F. is the resistance between clamps and material and the resistance of copper conductors. The E. M. F. required for iron and steel is nearly double that for copper and would be four times if equal projection were used for both.

A certain drop of E. M. F. will be found from the clamps to the specimens. This drop is rather low on material having naturally bright surfaces, as, for instance, copper, brass, german silver, tin

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or even cold rolled iron and steel. For a large class of work, however, especially in carriage hardware, the surfaces to be used for contact have a slight scale left after passing through the rolls, which has either to be removed by grinding or filing, or to be overcome by the E. M. F. of the current. In a good many cases the introduction of a special process of cleaning is deemed to be more expensive than to use a little extra power to work through the scale.

3. For uniformity of results the end pressure required to press the abutting specimens into each other at welding heat is of more importance than any of the former agencies; this is, in fact, the one which controls and rectifies any inaccuracies in the former conditions. If the pressure necessary for a given size and material is used, the weld cannot be performed until the metal has acquired the necessary plasticity to yield to the pressure. If for one reason or another, the E. M. F. and, consequently, the current should have been too strong, the time necessary for welding alone is affected, and in this case shortened. The bars will, however, be united at the same temperature and with the same force, whatever may have been the time required to bring about the necessary plasticity. The pressure will in some respects influence the heat by forcing the metals into each other at either higher or lower temperature, and by so doing cause the action to be interrupted at an earlier or later period as may be required.

The pressure required varies with the material and is approximately 1,800 lbs. per square inch for steel; 1,200 lbs. per square inch for iron; 600 lbs. per square inch for copper; it varies also with the area of cross-section as indicated by its being expressed in a function with the surface as one of the factors.

4. The interruption of the current as soon as the weld is completed is important for all easily fusible metals. When two copper wires are welded together the welded portion being increased in cross-section owing to the end pressure, if the current is not interrupted a large portion of the conductor on either side of the weld, including the latter, become heated and will melt and be torn asunder before any pressure device could follow and bridge the gap over.

The current should, therefore, be interrupted as soon as the weld is completed. It is also sometimes required that the parts to be welded should be of a certain predetermined length, in

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which case the interruption of the current as soon as the allowable distance has been reached is essential.

All these conditions are maintained constant in the automatic welder before us, which is the first commercial type of its kind. This welder is not entirely automatic in the strict sense of the word. The degree of automatic action has to be considered separately for each individual object. This machine contains, however, the leading features as covered by Professor Thomson's patent, June 26, 1888, No. 385,022, with a few improvements in mechanical construction.

The capacity of the machine is, nominally, copper wire, No. 6 to No. 17 A. G. It will, however, weld larger and smaller sizes. It weighs 130 pounds complete; the secondary is one solid copper casting of a cross-section resembling a hollow, square box with one of the sides removed. This casting is firmly screwed to an iron table. A saw cut at right angles to the plane of loop creates the two poles, one insulated from the table, the

Fig. 3

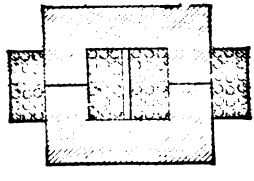
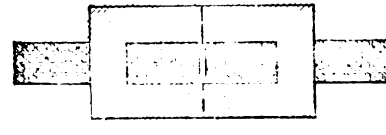


Fig. 4



other constituting a V-shaped bearing suitable to receive a sliding clamping device. The hollow part of the secondary receives the primary coil which is separately wound in a form and insulated with special care. Two U shaped laminated iron cores embrace the primary and secondary.

It has been found that the best form of transformer is the one in which the primary and secondary coils are co-axially placed in an iron core, so as to oblige all lines of force generated by the former to cut through the latter. If the two windings are placed side by side on an iron core or on opposite legs, as shown in Fig. 3, there is a tendency to form consequent poles at the point where the two windings meet, due to the leakage of lines of force. The leakage will depend upon the distance between the two legs, and upon the length of the magnetic circuit. It has been purposely increased and turned to advantage by Prof. Thomson, for obtaining constant current in the secondary, while the primary is supplied with constant E. M. F., as shown in Fig.

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4. When, however, constant E. M. F. in the secondary is required, it is important that this leakage should be decreased to a minimum.

Various forms of secondary may be employed to work consistent with the above principle. A few of these are shown in diagrams Nos. 5, 6, 7 and 8, in which cases the secondary is preferably a solid copper casting. The forms shown in Figs. 8 and 9, however, permit hard rolled copper plates to be used.

Fig. 5

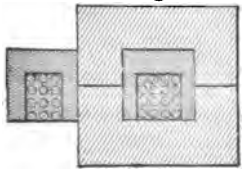


Fig. 6

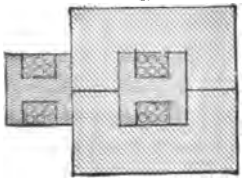
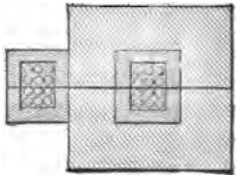


Fig. 7



For mechanical reasons and convenience, the forms shown in Figs. 5 and 6 are mostly used, and actual experience shows practically no leakage. This construction permits of removing the primary without disturbing the secondary in the least. It also gives the least possible self-induction for a given cross-section.

It is often stated that when large quantities of alternating cur-

Fig. 8

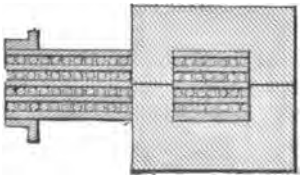
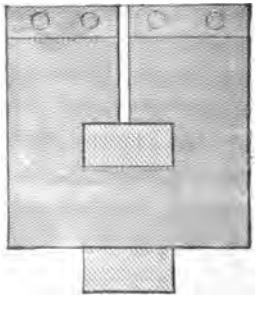


Fig. 9



rents have to be conveyed through copper conductors, it is important to have the same laminated or subdivided in smaller conductors to reduce self-induction. This may be true to a certain extent. The shape of the cross-section is, however, far more important than the lamination. An experimental compound conductor consisting of a number of flat copper ribbons in parallel showed a self-induction of *three* when the ribbons

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were closely packed, of *two* when separated into two parts, and *one* when spread open like a fan. The explanation for this was given to the Institute last year by Prof. Thomson when he showed the self-induction to depend mostly upon the length of the lines of force surrounding a conductor when traversed by intermittent or alternating currents.

Returning to the subject before us we find that the pole which is insulated from the table constitutes the stationary clamp. The uninsulated pole, which is considerably larger, has on its upper side a long V-shaped groove parallel with the axis of the

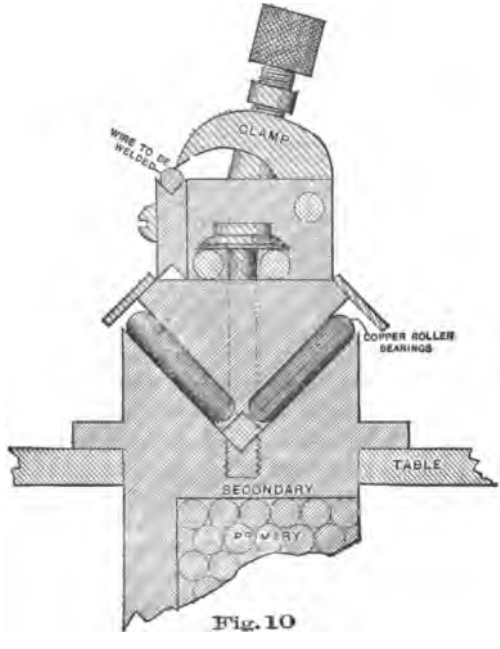


Fig. 10

secondary, Fig. 10. A movable copper block, also V-shaped, fits in the bearing and can be slid forwards and backwards in the same.

This movable block carries the second clamp. The current necessary for welding has to pass through this sliding contact. The welding of small copper wire or any other easily fusible metal, is a very difficult thing if special apparatus is not used. The current required is very large, several hundred amperes for wire not larger than No. 17 A. G.

The metal when it reaches welding heat readily melts away and

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has to be followed by the movable clamp so as to prevent the breaking of the circuit. This latter action when it occurs, is so violent that a special device is necessary to prevent injury to the coil in case of such a rupture. The moving clamp, in order to follow the softening of the metal has therefore to have as little friction as possible and yet has to make a good contact to carry the heavy currents. The clamp is furthermore required to move in true guides so as to abut the small conductors with their axes in line. The heating necessarily brought about when rapid and continuous welding is done must not interfere with the bearing and cause the carriage to stick through expansion.

All these conditions have been complied with in using the V bearings, the carriage being held down in contact by means of a heavy spring and a number of copper rollers being interposed between the carriage and the bearing. Fig. 10. The copper rollers are simple short pieces of $\frac{1}{4}$ inch hard rolled copper wire rounded at the ends. There are sixteen altogether, eight towards the front and eight towards the back of carriage, equally distributed on both sides of the bearing.

A stationary rod at the apex of the bearing prevents the interference of the two rows of rollers. Between the two sets of rollers in front and in back, a bolt passes, applying the spring pressure which forces the carriage into contact with the bearing. A pressure of 40 pounds may be employed, and yet the carriage will move freely. These sixteen rollers have to transmit a current of approximately 3,000 amperes. They absorb about 20 per cent. of the total energy, which loss is, however, fully balanced by the reliability and simplicity of the device. This loss is moreover only on the maximum sizes and becomes insignificant on small work.

An adjustable coiled spring pulls the sliding clamp towards the stationary one. In front and pivoted on a lever is the distance gauge which may be inserted between the two clamps. This gauge carries on a central disk a number of steel pins of varying lengths, but equal projection on either side of the disk. These projections, if inserted between the two clamps, give the necessary distance required for a given size wire, the disk against which the wires are abutted insuring equal projection of both ends to be joined. On the back of the apparatus a switch is located in a primary circuit, which is normally held open by a spring. By moving the handle to the right, the primary will be

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closed and the switch locked by a little catch underneath the table. A pin fastened to the movable clamp will lift the catch and release the switch, thus opening the circuit.

An intermediate lever between catch and pin operated by a sliding rule, which serves also as an index, permits of varying the point of cut-off, which has to be in a certain relation to the distance between the clamps. The position of cut-off, tension of spring, distance between clamps corresponding to each other, are marked with the same figure, which is also inscribed on a wire gauge fastened to the welder. By inserting a wire into the gauge, the number read will give the necessary adjustments at once.

If by imprudence, the switch should be moved to the right, while no stock is inserted and the clamps come in contact with each other, the switch cannot be locked and the fuse in the primary will be blown, without, however, causing any damage.

The insertion of the distance gauge between the clamps locks the switch so that the primary can only be closed after withdrawing the gauge.

The operation is as follows:

1. The wires to be welded are gauged.
2. The distance gauge and cut-off are set to correspond with the number on the gauge.
3. The movable clamp is moved to the right and the gauge inserted.
4. Both wires are securely clamped, care being taken to abut the ends squarely against the disk.
5. The gauge is withdrawn.
6. The switch is moved to the right.
7. The reactive coil is moved towards a position of minimum reaction, and restored to maximum after the weld has been completed.
8. The clamps are opened and the weld removed, after which the operation can be repeated.

If a good many welds of the same sized material are to be made, the reactive coil may once for all be set in a given position and the switch alone be operated. Welds made with the automatic machine have attained a uniformity not obtainable with the most skilled operators working without it. In fact, small, easily fusible wires can scarcely be welded with certainty with ordinary apparatus. For aluminum, especially, the automatic apparatus is needed.

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The reactive device used in connection with welders is of the type recently described by Prof. Thomson, in which a case is made to more or less cover the primary, the self-induction of which is to be altered. To obtain a still larger range, the windings of the primary can be coupled in series, or multiple series, or in multiple by a switch in the base of the coil.

As mentioned before, the welding of easily fusible metals may sometimes cause a rupture of the secondary circuit, which, owing to its violence and volume of energy may cause a burn-out of the primary if not guarded against. This danger is not very great in the automatic machine, since the end pressure does not depend upon the attention of the operator. A special device is, however, used as an extra precaution against all emergencies.

Breaking a high tension circuit rapidly is not easily done. An arc generally follows the break, and this lengthens the time of the rupture. If the voltage of the circuit to be broken is so low that over the slightest distance an arc cannot follow, the break will be instantaneous. This is the case with the secondary circuit of a welding transformer. The voltage being ordinarily only one volt, even if increased ten-fold, would not be able to maintain an arc. However, multiplied in the primary it will cause E. M. F. sufficient to pierce through the insulation as ordinarily used. This action is similar to that of a Ruhmkorff coil in which the interrupter is caused to break under oil or water. This discharge is taken care of by a special apparatus, the description of which I reserve also for another communication to the Institute.

While the machine before us is only one type embodying the principal features contained in all, others have been manufactured or are in process of construction in which the automatic character has been carried out even further, as in the welding of rings and chains. I am not permitted to give a detailed account of these latter at the present time, but would say that the present model in its first form, is able to produce 250 feet of chain in a day without any attendance to speak of, the plain wire being fed into the machine at one end and the complete chain coming out at the other.

The automatic principle is, however, not confined to small conductors. We have welders with 40,000 watts output, capable of welding 1 inch copper or 2 inch iron, constructed and working

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daily on that plan. The projections are determined by adjustable stops, the pressure, the most important of all, is hydraulic, and regulated by an automatic reducing valve, the exhaust being used for cooling the clamps at the same time. The primary is controlled by adjustable reactive coils from a constant potential circuit, and is interrupted at the proper time by the clamps. While not all machines are to-day operated on this plan, I am convinced that the evolution of the welding process tends in that direction, and that the welding in future will be in the full sense of the word a purely mechanical operation. This cherished idea of Prof. Thomson's, uttered a few years ago, has well been borne out by the experience gained in actual operation on a commercial basis.

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DISCUSSION.

PROF. THOMSON:—There is just one remark I would like to make, and that is, that Mr. Lemp is entirely too modest to put in any claims for his own work in relation to this matter. But I can say that he has worked diligently and faithfully in all the details of designing dynamos and proportioning the various arrangements, and has done a vast amount of very successful work, and I should like to testify to it here before the Institute.

THE PRESIDENT:—It seems necessary to postpone any further discussion of this paper at the moment, as there is here a paper by Mr. Lockwood which will be read by the Secretary.

Mr. T. D. Lockwood's paper on "The Industrial Utilization of the Counter Electromotive of Self-Induction" was then read. (*See page* 226 *ante.*)

THE SECRETARY:—Before closing, I move a vote of thanks to the authorities of the Massachusetts Institute of Technology for the many courtesies extended to us in providing facilities for the holding of our meeting in this city.

The motion was carried, and the meeting then adjourned.

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# AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

The 48th meeting of the Institute was held at the House of the American Society of Civil Engineers, 127 East 23d street, New York, June 17th, 1890.

THE PRESIDENT, PROF. W. A. ANTHONY:—The meeting will please come to order. Mr. Crocker has a resolution that he desires to offer.

MR. CROCKER:—I offer the following resolution, which has been recommended by the Council, to the Institute for consideration. The idea is that it shall be taken up for action at our next meeting, which will take place in the Fall. With your permission, I will read the resolution:

*Whereas*, It has been the custom in the nomenclature of electrical units to perpetuate the names of men who have contributed most to electrical science, and

*Whereas*, In the names thus far adopted the eminent services of Americans have not been recognized, therefore

*Resolved*, That in the opinion of the American Institute of Electrical Engineers, a just distribution of the honors thus bestowed necessitates a recognition of the splendid contributions to electrical science of one or both of America's great electricians—Benjamin Franklin and Joseph Henry; and,

*Resolved*, That this Institute will gladly co-operate with other bodies in this country and abroad to secure the general adoption of these names for electrical units; and,

*Resolved*, That the name of Henry should be given to the practical unit of self-induction, since he was the discoverer and greatest investigator of this phenomenon, and because this unit at present time is called a quadrant, which is merely a numerical value, and not a suitable name.

*Resolved*, That this Institute recommend to electrical societies and electrical engineers the general use of the name "Henry" for the unit of induction as being the quickest and surest way to secure its final adoption.

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DR. W. E. GEYER: I move that action on this resolution be deferred until the next meeting of the Institute.

MR. MARTIN.—I second the motion.

(Carried.)

THE PRESIDENT.—The next business before the meeting will be a paper on the "Efficiency of Transformers," by Calvin Humphrey and W. H. Powell. This paper will give you the result of some investigations conducted by these gentlemen at Cornell University. The paper will be read by Mr. Powell, and I now have the pleasure of introducing him to the Institute.

MR. POWELL then read the following paper.

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*A paper read at the 48th. Meeting of the American Institute of Electrical Engineers, New York, June 17, 1890.*

# EFFICIENCY OF THE TRANSFORMER.

BY CALVIN HUMPHREY AND WILLIAM H. POWELL.

In pursuing this particular line of investigation it has been our endeavor to throw some light, if possible, upon the general subject of transformers and upon the action of iron when magnetized and demagnetized by an alternating current of high peri-

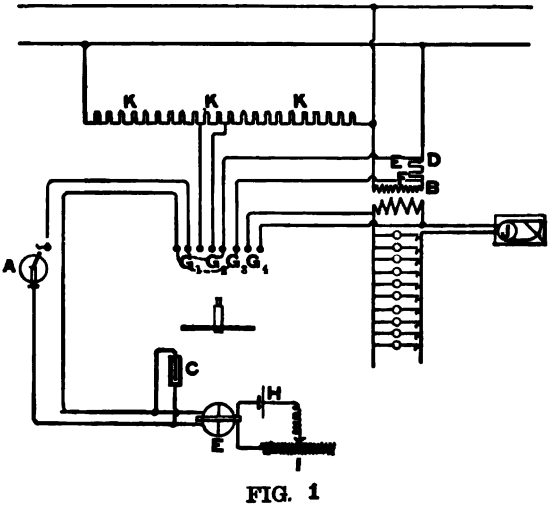


FIG. 1

odicity. And in order that the results obtained might have a practical bearing, the conditions of working were made to con form as closely as possible to the conditions under which transformer systems are operated in this country.

The question of the economy of the commercial converter as a transformer of energy has been frequently taken up, both from practical and theoretical standpoints, both with widely varying and conflicting results. The losses in the transformer of the

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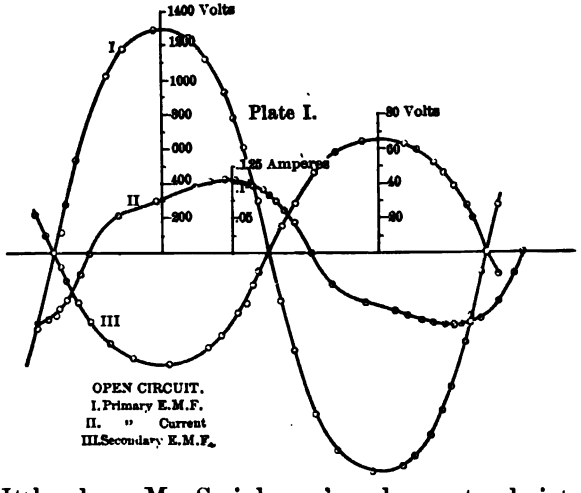
closed circuit type have been considered large and inevitable, so much so, in fact, that Mr. Swinburne has introduced in England a new form of open circuit transformer known as the "hedge-

OPEN CIRCUIT, PLATE 1.

| BRUSH. | S. E. M. F. | P. E. M. F. | P. C. |
|---|---|---|---|
| 18.5 | 21. Volts. | 450 Volts. | .104 Amperes. |
| 18.2 | 9. | 190 | .102 |
| 18. | 0. | 0 | .096 |
| 17.8 | 9. | 100 | .084 |
| 17.6 | 16.5 | 310 | .074 |
| 17.3 | 28. | 545 | .036 |
| 17. | 39. | 760 | 0± |
| 16.5 | 51.5 | 1020 | .0± |
| 16. | 59. | 1170 | .056 |
| 15. | 65. | 1285 | .074 |
| 14. | 61.5 | 1223 | .094 |
| 13.5 | 57. | 1130 | .102 |
| 13. | 47. | 925 | .104 |
| 12.7 | 40. | 780 | .104 |
| 12.4 | 27.5 | 565 | .102 |
| 12.2 | 20. | 330 | .098 |
| 12. | 9. | 245 | .096 |
| 11.8 | 0.± | 70 | .088 |
| 11.6 | 0.± | 0 | .078 |
| 11.3 | 14. | 300 | .056 |
| 11. | 27.5 | 560 | .046 |
| 10.5 | 44. | 890 | 0 |
| 10. | 56. | 1105 | .03 |
| 9. | 63.5 | 1265 | .072 |
| 8. | 63.5 | 1285 | .09 |
| 7.5 | 60 5 | 1215 | .098 |
| 7. | 53.5 | 1085 | .104 |
| 6.7 | 47.5 | 945 | .110 |
| 6.4 | 40. | 810 | .110 |
| 6.2 | 29. | 610 | .108 |
| 6. | 26. | 545 | .106 |
| 5.8 | 18 | 385 | .104 |
| 5.5 | 0 + | 110 | .098 |
| 5. | 14. | 260 | .074 |




hog." It has been Mr. Swinburne's endeavor to obviate the dissipation of energy in hysteresis and Foucault currents in a part of the magnetic circuit, by having that circuit closed through

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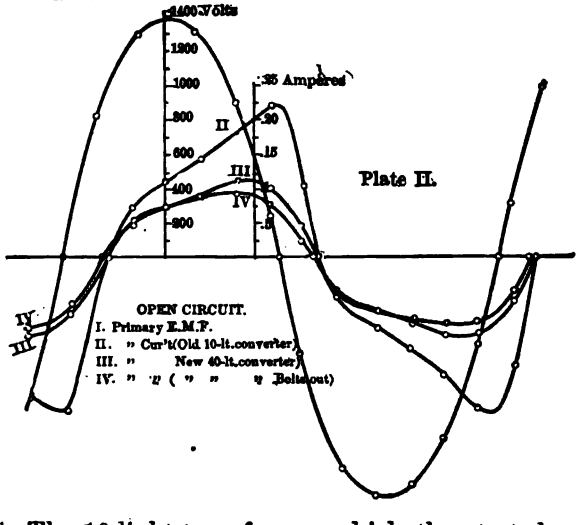
air. But as will be seen later, the perfection of the transformer is to be met in a better grade of iron, rather than in any radical change in design.

The results presented in this paper are of especial interest as being supplementary to the work of Prof. Ryan and Mr. Merritt in the same line, which was presented to the Institute last De-

PLATE II.

Open Circuit (Old 10-lt Converter.) (40-lt Converter. Bolts Out.)

| BRUSH. | P. E. M. F. | P. C. | BRUSH. | P. E. M. F. | P. C. |
|---|---|---|---|---|---|
| 19 | 825 | .196 | 19 | 775 | .098 |
| 18 | 0 | .225 | 18 | 0 | .089 |
| 17 | 840 | .042 | 17 | 845 | .0 |
| 16 | 1320 | .075 | 16 | 1245 | .048 |
| 15 | 1420 | .117 | 15 | 1355 | .074 |
| 14 | 1345 | .143 | 14 | 1290 | .09 |
| 13 | 1010 | .18 | 13 | 965 | .09 |
| 12 | 230 | .22 | 12 | 235 | .074 |
| 11 | 630 | .1 | 11 | 590 | .0 |
| 10 | 1115 | .058 | 10 | 1140 | .043 |
| 9 | 1395 | .1 | 9 | 1325 | .074 |
| 8 | 1420 | .13 | 8 | 1312 | .09 |
| 7 | 1195 | .17 | 7 | 1103 | .1 |
| 6 | 570 | .217 | 6 | 520 | .1 |
| 5 | 300 | .18 | 5 | 318 | .058 |
| 4 | 1060 | 0 | 4 | 1014 | 0 |




cember.[1] The 10-light transformer which they tested was found to have a remarkably heavy loss on open circuit, which was shown to be due almost entirely to hysteresis in the iron. The transformer gave an efficiency of 86 per cent. at normal load and an "all-day" efficiency of about 40 per cent.

In our work on a 40-light transformer of the same design,—

1 TRANSACTIONS, p. 1 *ante*.

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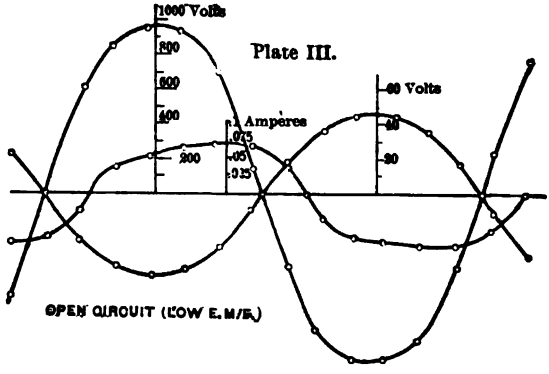
the two coils placed side by side in a core of laminated plates, Fig. 1,—but of more recent manufacture, the loss on open circuit was found to be about one half as great as in the 10-light transformer. Its efficiency reached 96.2 per cent. at normal load, and the "all-day" efficiency would be about 90 per cent.

The method employed in the work is substantially Prof. Ryan's method. The instantaneous values were obtained by means of a

PLATE III.

OPEN CIRCUIT, LOW E. M. F.

| BRUSH. | S. E. M. F. | P. E. M. F. | P. C. |
|---|---|---|---|
| 19 | 24·5 | 595 | .07 |
| 18 | 0. | 0 | .065 |
| 17 | 27·5 | 580 | 0 |
| 16 | 42. | 870 | .04 |
| 15 | 47. | 965 | .055 |
| 14 | 45. | 950 | .07 |
| 13 | 33. | 715 | .075 |
| 12 | 8. | 180 | .07 |
| 11 | 19. | 420 | .04 |
| 10 | 39. | 835 | .07 |
| 9 | 45. | 960 | .065 |
| 8 | 46. | 945 | .07 |
| 7 | 38. | 8 0 | .075 |
| 6 | 16.5 | 395 | .07 |
| 5 | 8. | 210 | .05 |
| 4 | 35·5 | 755 | 0 |




commutating device attached to the alternator. The device consisted of a wooden disc, mounted rigidly on the shaft of the alternator, with a steel contact at one point in its periphery, which made contact with a small piano-wire brush once every revolution. The holder carrying the piano-wire brush was attached to a second wooden disc carrying a pointer which moved over a scale and indicated the position of the brush for a given reading. By means of a clamp screw this second wooden disk carrying the

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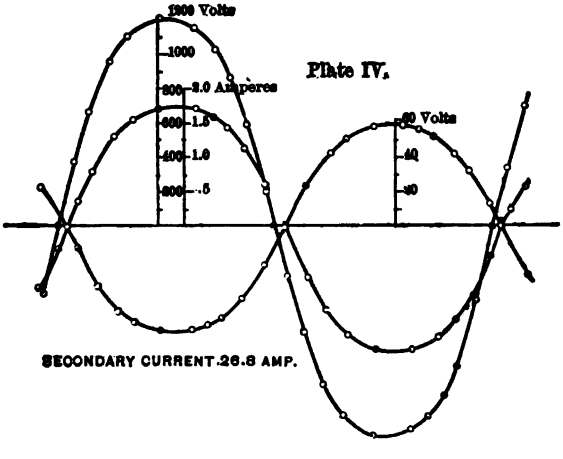
brush and pointer could be conveniently set at any point. Now since the steel contact in the wooden disc is fixed relatively to the armature, it must share the ever varying E. M. F. of the armature. Then evidently if the brush which completes the circuit

PLATE IV.

SECONDARY CURRENT, 26.8 AMP.

| BRUSH. | S. E. M. F. | P. E. M. F. | P. C. |
|---|---|---|---|
| 18.5 | 24.5 | 370 | .82 |
| 18. | 0. | 0 | .22 |
| 17.5 | 11. | 410 | .28 |
| 17. | 30.5 | 743 | .86 |
| 16.5 | 46. | 980 | 1.25 |
| 16. | 53. | 1110 | 1.55 |
| 15. | 59.5 | 1220 | 1.76 |
| 14. | 57.5 | 1145 | 1.74 |
| 13.5 | 54. | 1045 | 1.64 |
| 13. | 47. | 850 | 1.43 |
| 12.5 | 34. | 565 | 1.06 |
| 12. | 13. | 200 | .16 |
| 11. | 21. | 575 | .58 |
| 10.5 | 37. | 850 | 1.06 |
| 10. | 47.5 | 1060 | 1.44 |
| 9. | 58.5 | 1215 | 1.77 |
| 8. | 59.5 | 1195 | 1.80 |
| 7.5 | 56. | 1115 | 1.66 |
| 7. | 52.5 | 995 | 1.58 |
| 6.5 | 42. | 780 | 1.32 |
| 6. | 27. | 390 | .9 |
| 5.5 | 10. | 0 | .34 |
| 5. | 0. | 325 | .16 |




through the contact be altered in position, values can be obtained for different points on the curves of E. M. F. and current.

The Ryan quadrant electrometer was used to measure the primary E. M. F., secondary E. M. F. and primary current. A condenser was connected in multiple with the electrometer. The primary current was measured by the fall of potential through

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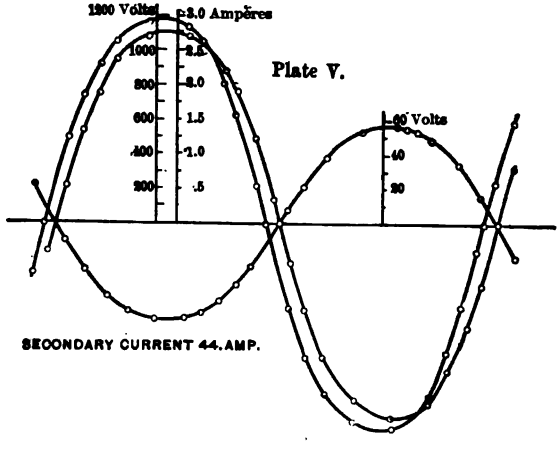
incandescent lamps placed in series with the primary of the transformer. These lamps were carefully calibrated with the standard instruments of the laboratory in order to know their resistance at different temperatures. Then knowing the resistance

PLATE V.

SECONDARY CURRENT, 44 AMP.

| BRUSH. | S. E. M. F. | P. E. M. F. | P. C. |
|---|---|---|---|
| 19. | 22.5 | 300 | 1.9 |
| 18. | 0. | 0 | .37 |
| 17.5 | 10. | 465 | .525 |
| 17. | 26. | 745 | 1.3 |
| 16.5 | 39. | 935 | 1.93 |
| 16. | 48.5 | 1075 | 2.4 |
| 15. | 55.5 | 1185 | 2.77 |
| 14. | 56. | 1150 | 2.67 |
| 13.5 | 51. | 1060 | 2.58 |
| 13. | 49. | 835 | 2.3 |
| 12.5 | 47. | 625 | 1.9 |
| 12. | 35.5 | 230 | 1.13 |
| 11.5 | 21. | 100 | .32 |
| 11. | 0. | 505 | .48 |
| 10.5 | 11. | 795 | 1.3 |
| 10. | 24.5 | 1015 | 1.98 |
| 9. | 40. | 1140 | 2.6 |
| 8. | 54. | 1200 | 2.84 |
| 7.5 | 57.5 | 1105 | 2.77 |
| 7. | 55.5 | 1030 | 2.67 |
| 6.5 | 51.5 | 805 | 2.23 |
| 6. | 45.5 | 510 | 1.69 |
| 5.5 | 32.5 | 130 | .97 |
| 5. | 17. | 250 | 0. |




of the lamps, and the potential difference at their terminals, the current flowing at once becomes known.

To measure the E. M. F., twenty-two 50-volt lamps were placed in series across the primaries. The electrometer was connected around two of these lamps, and the whole number calibrated in

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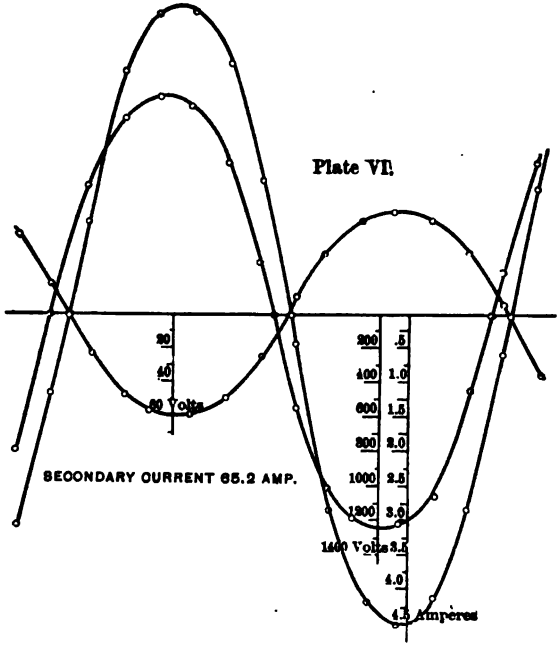
order to know just what part of the total impressed E. M. F. was measured. The secondary E. M. F. was measured direct. The secondary current was measured by means of an electro-dyna-

PLATE VI.

SECONDARY CURRENT, 65.2 AMP.

| BRUSH. | S. E. M. F. | P. E. M. F. | P. C. |
|---|---|---|---|
| 19. | 45. | 745 | 3. |
| 18. | 14. | 0 | 1.08 |
| 17. | 21. | 730 | 1.23 |
| 16. | 47. | 1120 | 3.45 |
| 15. | 58. | 1245 | 4.3 |
| 14. | 60. | 1195 | 4.35 |
| 13. | 51. | 905 | 3.8 |
| 12. | 26. | 240 | 1.85 |
| 11. | 8. | 550 | .4 |
| 10. | 40. | 1050 | 2.9 |
| 9. | 55. | 1225 | 4.1 |
| 8. | 59. | 1235 | 4.5 |
| 7. | 55. | 1070 | 4.25 |
| 6. | 37. | 475 | 2.83 |
| 5. | 0. | 235 | 0. |
| 4. | 29. | 900 | 2. |




mometer, which was carefully calibrated both before and after the experiments and was found to be constant. The commutating device was placed in series with the electrometer. Wires

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were run from the terminals from which the measurements were desired to a convenient switch-board. (Fig. 2.)

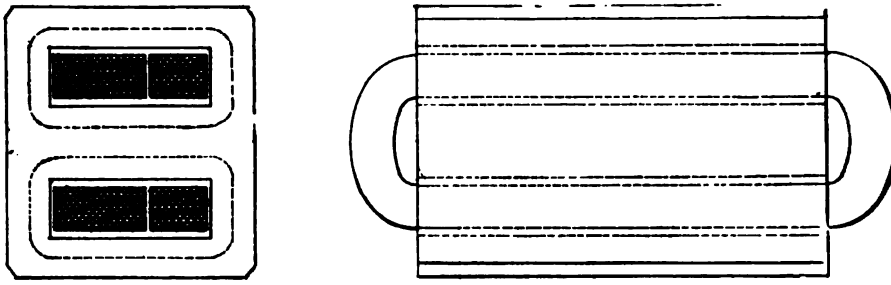


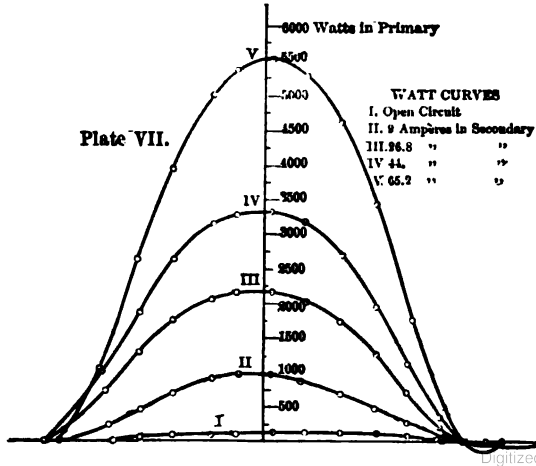
FIG. 2.

It is worthy of mention that this method which gives some thing so definite and fundamental in the treatment of the alter nating current has only come into use within the past year, and

PLATE VII. WATT CURVES.

AMPERES IN SECONDARY

| Open-Cir. | 9 | 26.8 | 44. | 65.2 | Brush. |
|---|---|---|---|---|---|
| —22.1 | 0 | 0 | 180 | 0 | 13. |
| —7.6 | 148 | 630 | 960 | 1020 | 17. |
| 30.6 | 400 | 1230 | 1750 | 2650 | 16.5 |
| 63.8 | 695 | 1720 | 2600 | 3860 | 16. |
| 82. | 880 | 2040 | 3080 | 4880 | 15.5 |
| 96. | 970 | 2130 | 3250 | 5350 | 15. |
| 105. | 960 | 2160 | 3320 | 5520 | 14.5 |
| 116. | 850 | 2020 | 3170 | 5250 | 14. |
| 113. | 700 | 1715 | 2700 | 4600 | 13.5 |
| 96.5 | 480 | 1220 | 1950 | 3440 | 13. |
| 65. | 250 | 600 | 1070 | 1800 | 12.5 |
| 22.8 | 50 | 115 | 253 | 443 | 12. |
| —10.5 | 0 | 0 | —350 | —96 | 11.5 |
| —25.2 | | 319 | 2500 | 220 | 11. |

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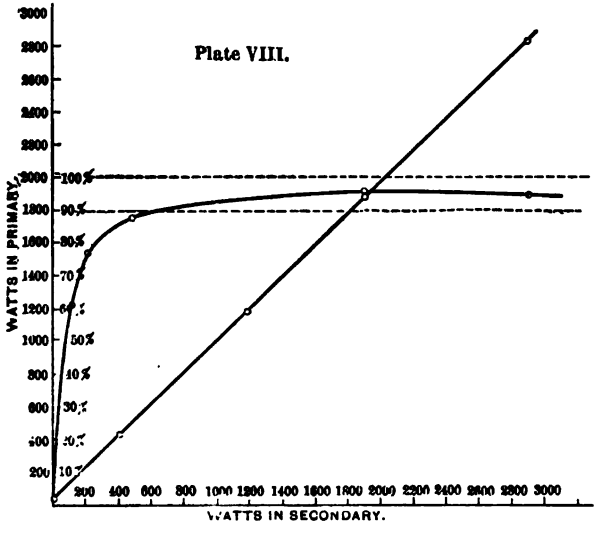
the task of getting true instantaneous values of the complete waves of E. M. F. and current which has always been considered too tedious for ordinary patience to deal with, was accomplished with ease in this work in forty-five minutes. A calibrated scale for the electrometer readings added very much to the facility with which observations could be taken.

The marked improvement of the 40-light transformer over the 10-light is due, we believe, to an improvement in the magnetic properties of the iron and a fewer number of turns in the coils, made possible by the better grade of iron. In the 10-light transformer Foucault currents were very effectually weeded out by




the interposition of sheets of paper between the laminated sheets of iron; in a 40-light, the oxide of iron on the surface of the plates was the only safeguard against Foucault currents.

The form and extent of the open circuit curves show the loss due to hysteresis and the slight loss also due to the Foucault currents. The presence of Foucault currents is indicated by the fact that the maximum of the primary current wave does not occur simultaneously with the zero of primary E. M. F., but a little before.

The primary current curve was again taken with the laminated plates loose and free to vibrate. The loss was about 10% less than in the former case (Plate II.) This is thought to be brought

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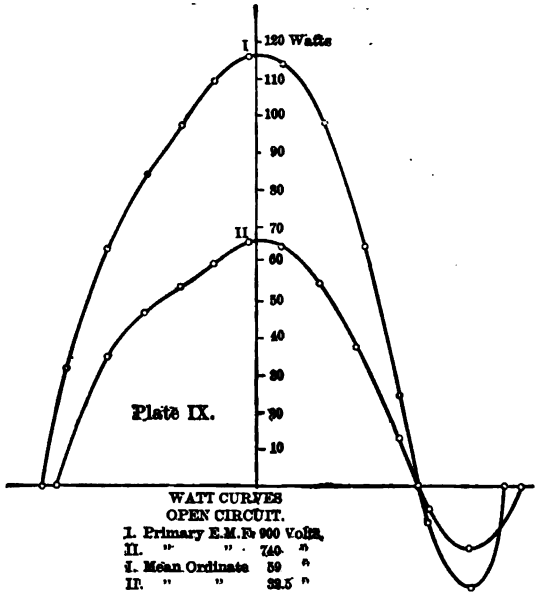
about by the decrease in the hysteresis loss, due to the increase of mechanical shock arising from the free vibration of the plates. The vibration was very perceptibly increased. The curve obtained is more regular in form indicating less hysteresis loss.

PLATE IX.

WATT CURVES. OPEN CIRCUIT.

| No. | 990 VOLTS. | 740 VOLTS. |
|---|---|---|
| 16.9 | 0. | |
| 16.7 | | 0. |
| 16.5 | 30.5 Watts. | 11.5 |
| 16. | 64. | 34. |
| 15.5 | 82. | 46.5 |
| 15. | 96. | 53.5 |
| 14.5 | 111.5 | 61. |
| 14. | 116. | 66. |
| 13.5 | 113.5 | 64. |
| 13. | 97. | 54. |
| 12.5 | 65. | 35.5 |
| 12. | 23. | 12.5 |
| 11.7 | 0. | 0. |
| 11.5 | —10.5 | —7.5 |
| 11. | —25. | —17. |
| 10.5 | 0. | 7. |
| 10.3 | | 0. |




The lag of the primary current behind the primary E. M. F. is seen to be greatest when the secondary circuit was open and decreases as a non-inductive load is introduced into the secondary circuit. This tendency of the lag of the primary current to de-

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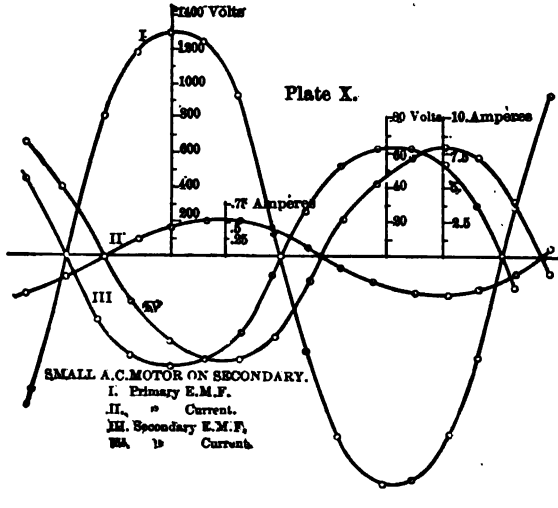
crease with increase of load, continues until the curve of primary current comes into unison with the curve of secondary E. M. F.

The secondary E. M. F. is in unison with the primary E. M. F. on open circuit and gradually falls behind as the load increases on the secondary. This is doubtless due to the leakage of lines of force arising from the enormous magnetizing forces at work in

PLATE X.

SMALL ALTERNATING CURRENT MOTOR ON SECONDARY.

| BRUSH. | S. E. M. F. | P. E. M. F. | P. C. | S. C. |
|---|---|---|---|---|
| 19 | 30. | 780 | .53 | 7.36 |
| 18 | 0. | 0 | .35 | 4.48 |
| 17 | 40. | 790 | 0 | 0. |
| 16 | 60. | 1195 | .25 | 3.52 |
| 15 | 64. | 1310 | .43 | 6.2 |
| 14 | 61. | 1240 | .53 | 7.5 |
| 13 | 46. | 930 | .54 | 7.5 |
| 12 | 11. | 140 | .42 | 5.76 |
| 11 | 26. | 570 | .12 | 0. |
| 10 | 55. | 1115 | .14 | 2.89 |
| 9 | 63.5 | 1305 | .375 | 4.47 |
| 8 | 63.5 | 1310 | .50 | 7.20 |
| 7 | 53. | 1095 | .55 | 8.32 |
| 6 | 27.5 | 560 | .49 | 7.20 |
| 5 | 14. | 290 | .25 | 3.52 |
| 4 | 47. | 950 | .0 | 0. |




opposition to one another in the primary and secondary circuits.

When an inductive resistance is introduced into the secondary circuit, the lag of the primary current is greatly increased, as shown by the set of curves in Plate X. The inductive resistance used in this case was due to a small alternating current motor. The curve of secondary current was also taken and found to lag

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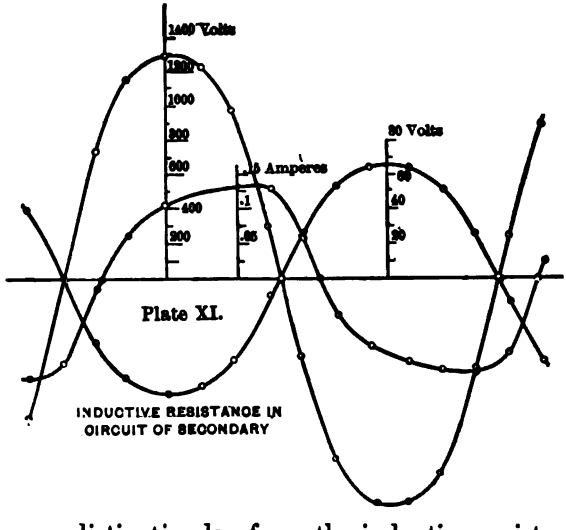
behind the secondary E. M. F. and to be in unison with the primary current. About 5.5 amperes flowed in the secondary and yet the lag of primary current is as great as on open circuit.

Plate XI shows the relation of primary current and primary E. M. F. when the secondary was closed through the secondary of a 20-light transformer whose primary remained open. The current

PLATE XI.

INDUCTIVE RESISTANCE OF SECONDARY.

| BRUSH. | S. E. M. F. | P. E. M. F. | P. C. |
|---|---|---|---|
| 19 | 39. | 790 | .147 |
| 18 | 0. | 0 | .196 |
| 17 | 40. | 770 | 0 |
| 16 | 61. | 1185 | .066 |
| 15 | 67. | 1310 | .108 |
| 14 | 63.5 | 1245 | .196 |
| 13 | 48.5 | 950 | .135 |
| 12 | 11. | 230 | .135 |
| 11 | 26. | 515 | .06 |
| 10 | 56. | 1105 | .05 |
| 9 | 66. | 1315 | .099 |
| 8 | 65.5 | 1295 | .12 |
| 7 | 56. | 1105 | .126 |
| 6 | 26. | 545 | .126 |
| 5 | 14. | 260 | .108 |
| 4 | 48. | 950 | 0 |




curve shows a distinctive lag from the inductive resistance and is altered in form to a great extent.

In Plate IX will be seen the watt curves for open circuit loss, one for 990 volts and the other for 740 volts. From the value of the mean ordinates it is seen that the loss varies strictly as the square of the impressed E. M. F.

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In Plate II is plotted to the same scale the current which flowed on open circuit in the case of the 10-light transformer and the 40-light transformer.

Plates IV, V, and VI show the curves of primary E. M. F. and current and secondary E. M. F. for different loads, from which the watt curves of Plate VII. are computed by taking the product of corresponding ordinates of primary E. M. F. and current.

The efficiency curve shown in Plate VIII. is the ratio between the energy of the primary circuit as indicated by the mean ordinate of the watt curve, and the energy of the secondary circuit as expressed by the product of the $\sqrt{\text{mean}^2}$ readings for E. M. F. and the current. The coercive force is equal to .8 C. G. S.

These considerations go to show that the loss due to the reversal of polarity of the iron, which perhaps must always be present may be reduced almost indefinitely by a proper study of the magnetic properties of the iron used.

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THE PRESIDENT.—As the next paper touches upon the same subject we will have it read before any discussion takes place. The paper is by Prof. Harris J. Ryan, of Cornell University. It is in continuation of the work which the Professor gave to you last winter.

PROF. RYAN then read the following paper :

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*A paper read at the 48th Meeting of the American Institute of Electrical Engineers, New York, June 17th, 1890.*

# SOME EXPERIMENTS UPON ALTERNATING CURRENT APPARATUS.

BY HARRIS J. RYAN.

It is well known that when the core of a transformer is heated under certain favorable conditions, the secondary will deliver electrical energy in amount considerably greater than when the core is not heated, and that this is done, too, without an increase of the energy that is supplied to the primary. In fact, we are told that on heating the core of the properly constructed transformer that there will follow a diminution of energy taken up by the primary and a considerable increase in that given out by the secondary.

In some recent experiments made in the Physical Laboratory of Cornell University, it was not possible to obtain the above effect. Mr. L. B. Marks, a student in electrical engineering at Cornell, made an apparatus that differed materially from the forms that were first made use of in which he found this phenomenon very marked.

For two reasons do we think that the details of the performance of Mr. Marks's apparatus will be of interest to the members of the Institute—first, that they indicate clearly the source of energy in the phenomenon observed with his apparatus, and second, that they show in exaggerated form certain phenomona that must be done away with in a transformer that is to be used for incandescent lighting.

A good idea of the apparatus will be obtained by a glance at Fig. 1. The core consisted of nine well-rusted rings 1.1 cms. thick and of a mean diameter of 17 cms. each. The number of turns on the primary was 500; on the secondary 155; size of bare copper wire in each was No. 16 B. & S. gauge. The wire

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was insulated with asbestos paper, and because of its thickness, the primary and secondary turns with their insulation occupied a space of abnormal proportions. The resistance of the primary was 1.65 ohms, and that of the secondary was 0.71 ohms.

The maximum magnetization used in the core in any of the experiments here described, was not above 3,000 lines per square cms.

The diagrams, Figs. 2, 4, 5 and 6, represent graphically the observations that were made with the apparatus.

From these diagrams are deduced the following results:

Fig. 2. Secondary open; no extraneous heat applied; temperature of the core, 97.5 C; primary E. M. F., 75.6 volts; secondary E. M. F., 16.4 volts; ratio $\frac{75.6}{16.4}$ 4.6; secondary current, 0.0.

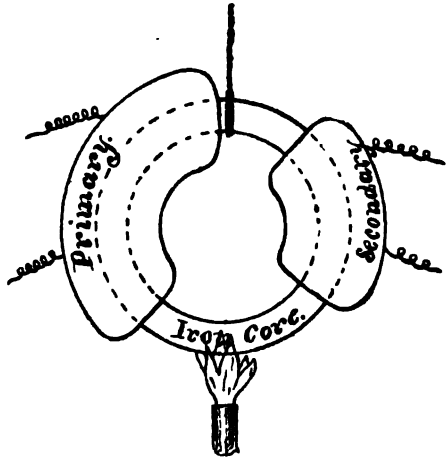


FIG. 1.

Fig. 4. Secondary open; core heated; temperature of core, 300 C; primary E. M. F., 99.4 volts; secondary E. M. F., 24.5 volts; ratio, $\frac{99.4}{24.5} = 4$; secondary current, 0.0.

Fig. 5. Secondary closed; no heat applied; temperature of the core, 100.0 C; primary E. M. F., 89.3 volts; secondary E. M. F., 11.9 volts; ratio, $\frac{89.3}{11.9} = 8.1$. secondary current, 2.0 amperes.

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Fig. 6. Secondary closed; core heated; temperature of core, 270 C; primary E. M. F., 95.7 volts; secondary E. M. F., 13.4 volts; ratio, $\frac{95.7}{13.4} = 7.1$; secondary current, 2.4.

TABLE 1.

| | | Temp. | Primary E. M. F. | Primary Watts. | Second'y Watts. |
|---|---|---|---|---|---|
| 2. | Secondary open, no heat applied to core. | 97.5° C | 75.6 | 87. | 0.0 |
| 4. | Secondary open, heat applied to core .. | 300.° C | 99.4 | 88. | 0.0 |
| 5. | Secondary closed, no heat applied to core. | 100.° C | 89.3 | 139. | 24. |
| 6. | Secondary closed, heat applied to core... | 270.° C | 95.7 | 129. | 36.7 |

Data are presented in the latter part of this paper showing that it is correct to assume for small ranges that the loss in the core is proportional to the square of the primary E. M. F.

We can, therefore, deduce from Table 1 the results that would

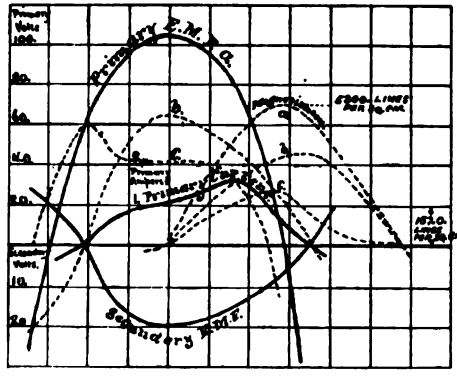


FIG. 2.

have been obtained with 90 volts as the primary E. M. F. for the four experiments.

TABLE 2.

| | Temp. | Primary, 90 volts. 120 reversals per sec. Loss in core. | | Primary Watts | Secondary Watts. | |
|---|---|---|---|---|---|---|
| 2. | 97.5 C | 122. | | 122. | 0.0 | |
| 4. | 300. ° C | 72. | | 72. | 0.0 | |
| | 270. ° C | 79. | (estimated) | 79. | 0.0 | |
| 5. | 99. ° C | 117. | | 131. | 24. | corrected for resistance of secondary. |
| 6. | 270. ° C | 80. | | 116.7. | 36.7 | |

These figures in Table 2 show clearly that the loss in the core is greatly diminished when its temperature is elevated, *i. e.*, when heat is applied, and that the loss in the core is practically independent of the output. The results indicate that with the

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secondary open and the primary at a difference of potential of 90 volts without heat applied, the core came to a temperature of 97° C., and dissipated 122 watts; then by the application of heat with the Bunsen burner, as indicated in Fig. 1, the temperature of the core was raised to 300° C, and was found to take up 72 watts. Now, if we assume the change in watts dissipated in the core to be approximately proportional to the changes in temperature that produced the same, then we see by estimation that 79 watts would have been dissipated by the core at 270° C, while 80 watts were found to have been dissipated by it at that temperature when the secondary was closed, and gave an output of 32 watts.

It is perfectly plain, therefore, why we can close the secondary, take from it 32 watts, elevate the temperature of the core 170° C, and have the primary take up 5 watts less than

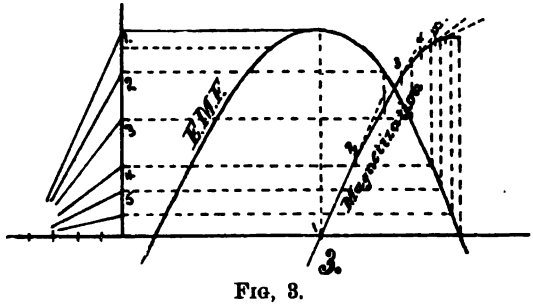


FIG. 3.

when the secondary was open, and the core at the lower temperature.

Since the effect is due only to the fact that the core takes much less energy at higher than at lower temperatures, and since the core can dissipate energy through Foucault current and hysteresis phenomena only, it is due to a decrease of the total energy dissipated through changes in the above phenomena.

A rise of temperature in the core will increase its specific resistance, and therefore diminish the energy dissipated by Foucault currents. For decided degrees of magnetization it is known that the permeability of iron increases when it undergoes a rise of temperature. It was thought probable, therefore, that the energy dissipated per cycle of magnetization and demagnetization would be decreased with an increase of temperature.

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Experiments were made in the Physical Laboratory of Cornell University by Arthur Herschel on the hysteresis at high temperatures of a cast-iron ring, 12.3 cms. in diameter that furnished a closed magnetic circuit, the length of which is 38.5 cms. The ring was wound with 30 turns of No. 8 wire cable that had a mica insulation.

The highest temperature to which the ring was subjected was 360° C. The results of those experiments are represented graphically in Fig. 7.

One interesting thing about these results is that for degrees of

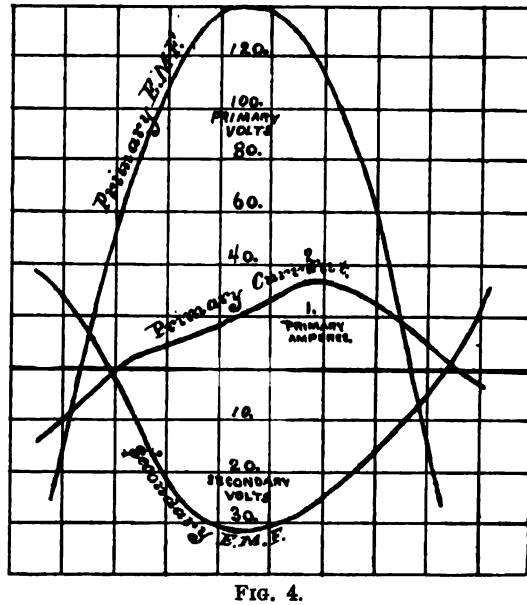


FIG. 4.

magnetization below 2,000 lines per square cm. the variation of temperature below 360° C. does not change the magnetic character of the iron by an observable amount. For if wrought iron behaves in a similar manner then the decrease of energy dissipated in the apparatus of Mr. Marks was not due wholly nor in part to a diminution in the hysteresis of the iron. It was therefore due entirely to the diminution in Foucault currents, caused by the change of the resistance of the iron. A liberal estimate for the hysteresis of the core is twenty watts, whence the Foucault energy dissipated by the core at 100° C and 90 volts was 102 watts, and at 270° C and 90 volts it was 60 watts.

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The range of temperature that produced this change was 170°. The magnetization for each condition is the same, so that it is fair to assume that E. M. F. setting up the Foucault currents is the same, and that, therefore, the energy dissipated by Foucault currents will diminish as the resistance of the iron is increased by the elevation of its temperature.

This gives us a rough determination for the temperature coefficient of the iron to be .4 of one per cent. per degree centigrade, which agrees with Matthiessen's determination and furnishes a fair check upon the conclusion just arrived at.

The second interesting feature about the performance of Mr. Marks's apparatus lies in the fact that the ratio of primary to secondary turns was 3.2, while the relation of primary to secon-

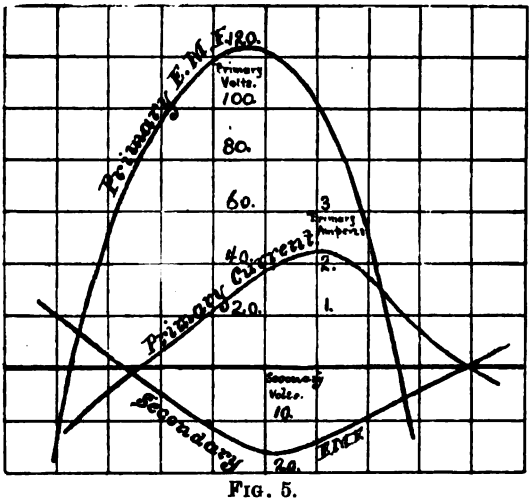


FIG. 5.

dary E. M. F.,s varied from 4 to 8. In this it exhibited exceedingly bad regulation so that by examination of the diagrams 2, 4, 5 and 6, we can see in exaggerated form the trouble it is so hard to become rid of in transformers to be used for incandescent lighting. Any one of these diagrams shows that a large portion of the lines of magnetization that were set up about the primary was not set up about the secondary. That is to say, the counter E. M. F. that is produced in the primary is due to the magnetization through it, that also took place through the secondary, plus the variation of magnetization that was set up in its own air space and that leaked by the secondary through the air. When

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the transformer furnishes current this difference becomes greater and greater, because of the increased current in the primary and the setting up of a counter magnetization by the secondary current in its own air space that still further reduces the magnetization through it.

Fig. 1 shows the primary disposed on one side and the secondary on the other side of the annular core. The insulation was provided by thick asbestos paper that produced large air spaces between the turns in which magnetization was provided.

In Fig. 2, E. M. F., curve *b*, is the counter E. M. F. in the primary produced by the magnetization through it that also took place through the secondary and which is obtained by multiplying

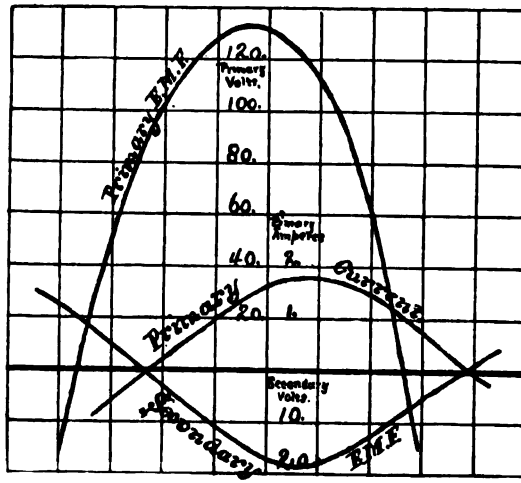


FIG. 6.

the secondary E. M. F. by 3.2, the ratio of the turns; E. M. F. *C* is the curve of counter E. M. F. in the primary that was produced by magnetization through the primary that did not take place through the secondary. This is obtained by subtracting E. M. F. *b* from E. M. F. *a*; E. M. F. *c* is seen to be approximately proportional to the rate of change of the primary current, which suggests magnetization that is set up through the primary that is proportional to the primary current, or that which is set up in the air, or in a magnetic circuit compounded of iron and air.

In the same figure the curves of magnetization *a* and *b* are ob tained graphically from the curves of E. M. F. *a* and *b* by the method shown in Fig. 3.

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This method is found to be fully as accurate and requires much less time and is more simplified than the analytic method, making use of Fourier's theorem. By substracting $b$ from $a$ we obtain $c$, the curve of magnetization that was produced through the primary and not through the secondary. This curve of magnetization, $c$, is seen by the diagram to be of about the same form as the current curve, but to lag behind the latter, which indicates that it was magnetization that was produced through air, and air and iron

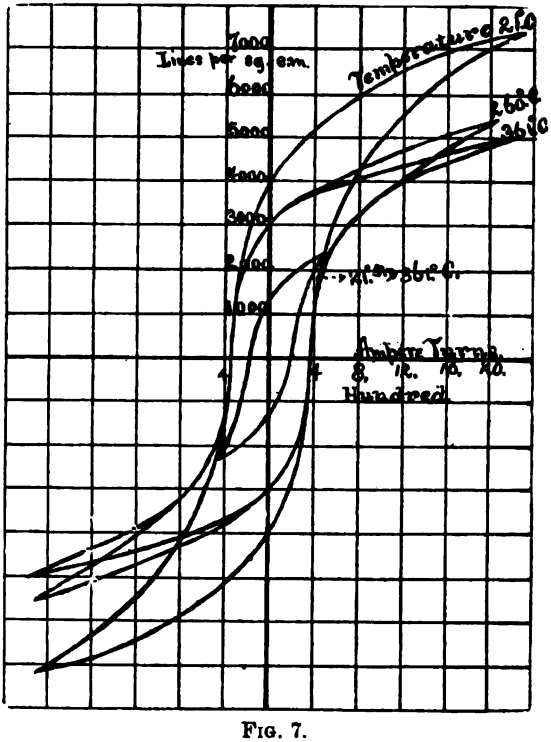


FIG. 7.

During the discussion at a recent meeting of the Institute the question was asked whether measurements of Foucault currents and hysteresis, as separated from each other, had ever been made.

There can be no doubt but that we do have separate determinations of those quantities when we have determined the energy dissipated in a magnetic circuit of iron by rapid cycles of magnetization and demagnetization, and the energy dissipated by

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static hysteresis for the same rapidity and degree of magnetic changes as determined from a Ewing card, observed through slow magnetization and demagnetization.

Figs. 8 and 9 are two good illustrations of such determinations.

In Fig. 8, the outer card represents the card obtained from the existing current and magnetization curves taken carefully at 138 periods from the 10-light transformer upon which the tests were made that were communicated to the Institute by the writer at the last December meeting.[1] The inner card drawn in

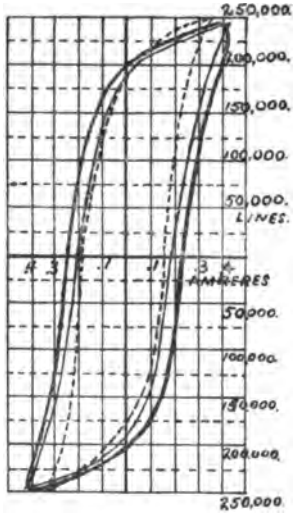


FIG. 8.

a full line in Fig. 8, is the Ewing card of static hysteresis. This transformer on being taken apart was found to have its discs insulated with paper so that the statement made by the writer in December in regard to the insulation of the transformer was erroneous in this particular. Foucault currents should therefore be found to be quite absent as the diagram in Fig. 8 indicates. A study of these cards does not reveal that which can be recognized as a trace of viscous hysteresis and they differ only by an amount of Foucault current energy that is represented by a small current lagging approximately an eighth of a period behind the primary impressed E. M. F.

1. TRANSACTIONS p. 1 *ante*.

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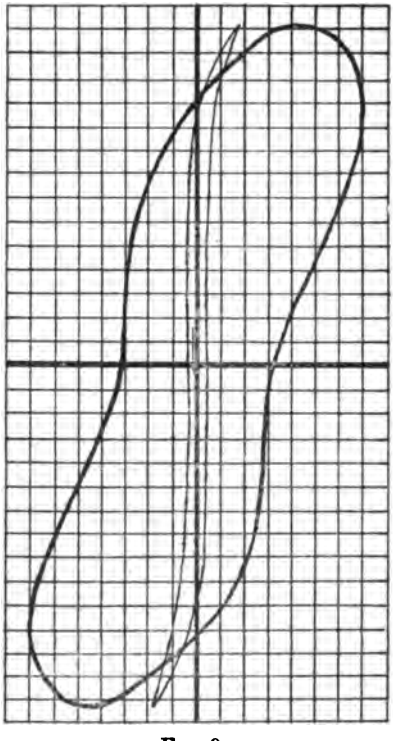

FIG. 9.

In Fig. 9. the outer card is deducted from the current and magnetization curves that are represented in Fig. 12. These curves were obtained with 195 alternations per second from a cast iron ring 8. 6 cms. in diameter, and 2. 7 sq. cms. in cross-section, wound with 200 turns of wire that had a negligible resistance.

In Fig. 9, the inner card is the card of static hystersis.

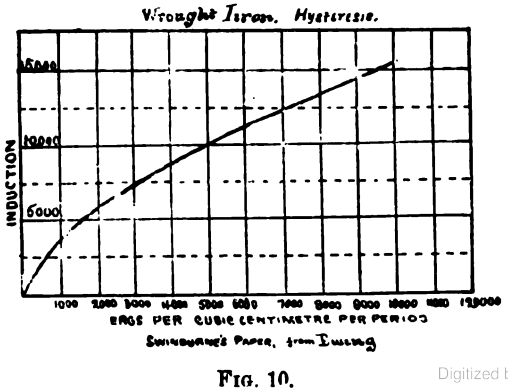


FIG. 10.

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In Fig. 12, the lower broken current curve is that of the exciting current curve drawn in from the inner card of Fig. 9. By subtracting this current from the one that was observed, we obtain the upper broken current curve, which is the current that exists to supply the Foucault current energy in the core. The point to be noticed from the two extreme cases here taken up is that in each case the curve or current supplying the Foucault current energy is about one-eighth of a period behind the impressed E. M. F.

Messrs. Fortenbaugh and Sawyer, students in electrical engineering at Cornell University, made determinations, the results of which are given in Table 3, of the amounts of energy that

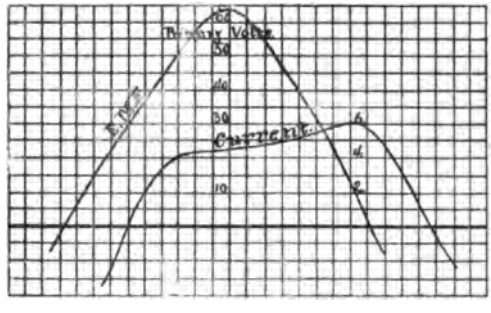

FIG. 11.

TABLE 3

| Coil of wire B. & S. G. | | Area of coil sq. cms. | Periodicity. | Magnetization per sq. cm. | Loss Watts per cu. cm. |
|---|---|---|---|---|---|
| 1 | 12 | 5. | 169 | 5,300 | .18 |
| 2 | 12 | 5. | 177 | 8,560 | .46 |
| 3 | 12 | 5. | 177 | 11.130 | .75 |
| 4 | 16 | 4.9 | 173 | 6.000 | .14 |
| 5 | 16 | 4.9 | 175 | 9 430 | .33 |
| 6 | 16 | 4.9 | 167 | 10,930 | .43 |
| 7 | 16 | 4.9 | 93 | 7,250 | .10 |
| 8 | 16 | 4.9 | 92 | 13,360 | .41 |
| 9 | 16 | 4.9 | 45 | 13.000 | .10 |
| 10 | 24 | 3.56 | 175 | 8,150 | .19 |
| 11 | 24 | 3.56 | 53 | 8.760 | .12 |
| 12 | 36 | 3.14 | 173 | 9,200 | .16 |
| 13 | 36 | " | 173 | 14.900 | .29 |
| 14 | 36 | " | 173 | 18,000 app, | .48 |
| 15 | 36 | " | 96 | 10,700 | .15 |
| 16 | 36 | " | 92 | 17.800 | .33 |
| 17 | 36 | " | 47 | 18,000 app. | .13 |
| | (Cast iron diam., 8.6 cms ) | | | | |
| 18 | 36 | 2.7 | 160 | 4,920 | 1.50 |

are taken up per cu. cm. in wrought-iron wire cores, of different degrees of lamination, at various degrees of magnetization, and at

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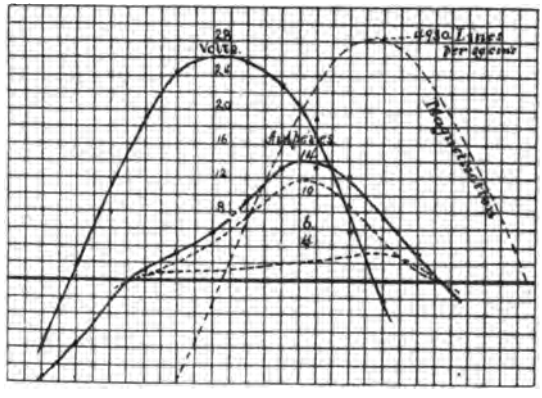


FIG. 12.

different periodicities in which the oxydized surface of the iron was depended upon for insulation. They made use of four iron wire rings the mean diameter of each of which was 8.9 cms. and on each of which were wound 200 turns of wire that had a negligible resistance.

Figs. 11. and 13, are given for illustrating the extreme varia

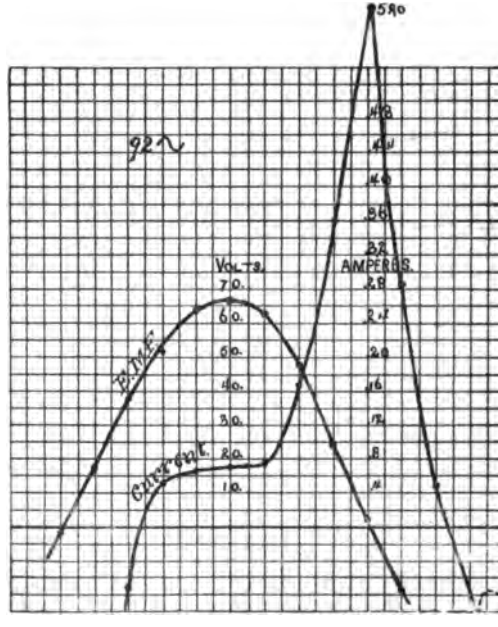


FIG. 13.

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tion in the character of the exciting current in going from the lowest to the highest degree of magnetization.

The results show on account of the presence of Foucault currents to a larger extent for the higher degrees of magnetization, a variation in losses as the square of the periodicity and the square of the magnetization. The results obtained with the several cores at the periodicity of 175 have been plotted in Fig. 14.

The core of No. 36 wire agrees closely with Ewing's determination of static hysteresis for moderately soft wrought-iron, and is therefore entirely free from Foucault currents. It is interest-

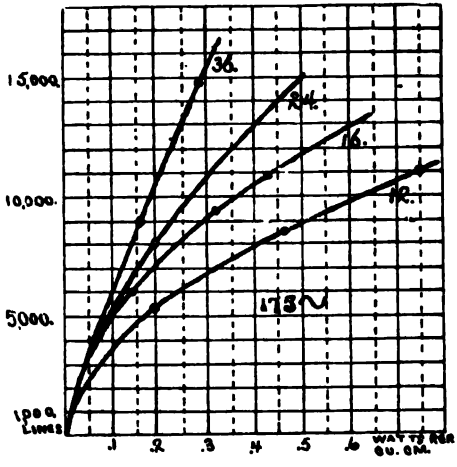


FIG. 14.

ing to note that for the cores of No. 36, No. 24 and No. 16, there is but little difference in the losses for degrees of magnetization below 4,000 lines per centimeter.

Likewise that for the higher degrees of magnetization it is seen that the loss is proportional to the magnetization as Ewing's results on static hysteresis given in Fig. 10 indicates they should be.

Diagram 13, shows the effect of compelling the magnetization to be carried above the bend of the characteristic curve of the iron.

## DISCUSSION.

THE PRESIDENT:—These two papers are before you now for discussion. We shall be glad to hear from any members of the Institute or others who have anything to say upon the subject.

DR. GEYER:—I do not recollect Prof. Ryan stating how those

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lines of which figure 14 gives a graphic representation were determined. I would ask him to please state that?

PROF. RYAN:—They were determined in the same manner that the loss is determined in the transformer that was described—that is, by observing the curves of current and E. M. F., and deducting Watt curves from them.

DR. GEYER:—You got simultaneous currents and electromotive force curves?

PROF. RYAN:—Yes, sir.

DR. GEYER:—And all these curves on the first half of the page were determined by the same general method?

PROF. RYAN:—Yes, sir.

DR. GEYER:—Do I understand you to say that the curve of primary in fact would vary with every variation in the running of the machine?

PROF. RYAN;—Not in every variation of the running of the machine; but it was observed to vary when the field excitation of the machine was changed. The excitation was changed in order to get a change of E. M. F. I do not suppose its performance would be found to be just like a large machine.

DR. LOUIS BELL:—I would like to ask Mr. Powell about the iron in that transformer. I confess that I have a good deal of faith in iron good enough to give an all-round efficiency of 90 per cent. I would like to know how the thickness of the iron in that forty-light transformer compared with the thickness of the iron in the ten-light transformer; in other words, whether he determined in detail its magnetic properties aside from those given on this paper?

MR. POWELL:—We did not measure the thickness of the iron, but as far as I am able to judge, it was of the same thickness; and, in regard to that Ewing card, we took several, one after another, and they are all practically the same. That was as far as we went in studying the properties of the iron.

MR. TOWNSEND WOLCOTT:—In any of these curves of hysteresis did you obtain evidence of viscous hysteresis?

PROF. RYAN:—No, sir.

MR. WOLCOTT:—That result is very interesting and seems a little extraordinary to me.

PROF. RYAN:—What I mean by the matter is merely this; that the agreement of the card of static hysteresis is so close with that observed at the high rate of magnetic change that from that I was of the opinion that one could see very little effect due to viscous hysteresis, unless I have a wrong impression as to what viscous hysteresis is.

MR. WM. STANLEY, JR.:—Professor Ryan has spoken of the constant polarix. If you look at Humphrey and Powell's paper, on the left hand side near figure 2 there is a section of the converter. A smaller coil represents the secondary, and the larger coil the primary. That same action described by Prof. Ryan

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takes place in this converter. The secondary heads off the lines from the primary from passing through the secondary circuit. This causes a drop of potential in the converter between open circuit and a full load of about two volts over that which is found by the wasting of energy in the converter. I would like to ask Prof. Ryan what was the maximum number of lines per square centimetre that he used in the magnetization curves of the forty-light transformer?

PROF. RYAN:—I do not know that I can answer that question exactly, but I am very sure that the maximum number that Messrs. Powell and Humphrey used in their experiments was not higher than about forty-five hundred lines per square centimetre. The diagram that is presented here is incorrect, Mr. Stanley, and the figures given there should be multiplied by about four-tenths and the proper values would then be attained.

MR. STANLEY:—I think it is the general practice to use about 3,000 for magnetization.

MR. JOSEPH WETZLER:—I did not quite catch what Prof. Ryan described as the difference in the ratio of electro-motive force in the primary and the secondary in his experiments.

PROF. RYAN:—To what the difference is due?

MR. WETZLER:—Yes, sir; to what it would describe.

PROF. RYAN:—(Indicating a figure on the blackboard). There is a great deal of air space surrounding the wires of the primary and those of the secondary, and while the magnetic resistance of air is very much higher than that of iron, that of the air circuit is very short and a certain amount of magnetization is set up about the wires of the primary in its own air space. On account of the Foucault currents that are set up on this side a certain number of lines will often pass down between the primary and the secondary coils, and since the secondary does not embrace all of the lines of force therefore, that are set up in the primary, the electro-motive force that is produced in the secondary will not be that which the ratio of the terms of the primary to the terms of the secondary would indicate. That is, if we had taken the 155 turns and had wound them right in here in the same position that the turns of the primary were wound, then we should have obtained a ratio of transformation that is exactly equal to that of the ratio of the turns.

MR. STANLEY.—Isn't it possible that the air space increases the lag of the secondary current? Three or four years ago I made a transformer that would give a constant current on the secondary by making the same device that Prof. Ryan has shown and bringing the center web down. Prof. Thomson also did something of the kind But if the secondary coil has a local magnetic circuit wherever it is so placed upon the core that the air resistance around the secondary current is low, then it changed the lag of the secondary current and you get a constant secondary current constantly applied to the primary potential.

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PROF. RYAN.—We have observed just that very thing in making our experiments with transformers also.

MR. WETZLER.—Mr. Stanley has remarked that in order to overcome the leak that occurs when the wires are wound side by side they have been super-posed. I would like to know what the effect of that increased length of wire would be which would be required in such a case?

MR. STANLEY.—If one were wound on top of the other, the secondary would be proportionately shorter and the primary proportionately longer.

PROF. RYAN:—I would like to say a word further in regard to the point referred to by Mr. Stanley, and that is the large amount that the secondary electromotive force fell off in these experiments of Mr. Marks, which shows the point quite well, I think, that Mr. Stanley has brought up. That is, when you allow the secondary to furnish current, then lines of force are set up in the air space of the secondary, counter to the lines of force that are already set up through the core, and since they are in opposite directions, what you get so far as electromotive force is concerned in the secondary is virtually the sum of the two, and that therefore when you load down the secondary, the secondary difference of potential will go right on down and have no relations hardly to the internal resistance of the apparatus.

MR. STANLEY:—Has Prof. Ryan ever considered the problem of transforming alternate currents by using high periods, possibly 10,000 a second, and no iron? I think that is a very good field for investigation.

PROF. RYAN:—We have never attempted anything in that line, I think, though, it is a very interesting field.

A MEMBER:—I notice in some of these curves of magnetization, as they are called, that they seem to be followed by the sine law, and I did not catch very clearly how they were obtained, whether by experiments or not. But if we plot out from the hysteresis curves of Ewing's curves of magnetization resulting from a magnetization current which follows the sine law, the magnetism resulting from that will not by any means follow the sine law. It will be a rather blunt curve, coming up sharply at the start, and then remaining near the maximum value for quite a length of time. That is, it will be flat on top. I would ask Prof. Ryan if any such result has been obtained in any of his researches or experiments, or how this curve was obtained that he has here?

PROF. RYAN:—In answer to the one question I would say that we have taken what is usually called a "choke coil," and, as it were, forced an alternating current of a sine curve through it and obtained such a difference of potential as would indicate the curve of magnetization; then, when you work back by means of this curve of electromotive force, which is equal to the change of magnetization, it shows just such a curve of magnetization as

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you say you get by the card of static hysteresis of Ewing. And with regard to the manner in which these curves of magnetization here have been obtained, I would say that in some cases they have been obtained analytically by determining an equation compounded of sine curves that express the curve of electromotive force that was actually obtained, and from that, determining the curve of magnetization, which curve of magnetization is merely a curve whose rate of change of ordinates is proportional to the curve of the electromotive force that was actually observed. You have a different case in a transformer where the resistance of the primary is practically ineligible as compared to the full pressure on the primary. There, the magnetization must follow the law which is defined as the rate of change in the curve of primary electromotive force. It has to do that, regardless of what current must flow to produce such magnetization in the circuit of the transformer. And that is quite well brought out in one of the diagrams which I have here. (Here the Professor illustrated from a diagram on the blackboard). We have here a coil sometimes called a "choke-coil," but merely a magnetic circuit wound with a certain number of turns of wire that had quite entirely a negligible resistance, and it was subject to a certain difference of potential, and if the resistance of the coil be negligible, then current will flow at any instant to make the rate of change in magnetization in that magnetic circuit proportional to the difference of potential to which it is subjected. The consequences were that at this point (indicating) this coil of No. 36 iron wire came to a magnetization of about 15,000, and it took a considerable number of ampere turns to raise its magnetization beyond that. In some cases I know that it went very much higher than that, in making the magnetization follow a sine curve throughout that side (indicating).

A MEMBER:—I would like to learn if Professor Ryan knows about what temperature the increase of economy disappears by heating the core on account of the magnetic property of the iron?

PROF. RYAN:—I think that is a matter that is entirely known. You see since this effect can only come in, when you have a large quantity of energy dissipated by Foucault currents, that in the case of commercial transformers there would be no such limit. Mr. Herschel's results show, too, within the ranges of magnetization that would be used in a commercial transformer that any temperature to which it would be subject would not change the hysteresis by an observable amount, and therefore I think that so far as a practical view is concerned, such limit would not be sought.

MR. CHARLES STEINMETZ:—Professor Ryan says they could find the magnetization of the core by calculating an analytical expression given by the scope of electromotive force. I would ask whether he found in this analytical expression of the primary

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electromotive force special peculiarities. For instance, that the second curve of hysteresis has a special check?

PROF. RYAN:—I remember last summer of our having taken some curves and drawn them out on cross-section paper—that is, the various orders and the higher orders—and I do not remember any peculiarities. We drew then out as sine curves, and when we added them up we got the real curve of electro-motive force. There is a matter that I should like to speak of, and that is that when a curve of electromotive force is flat at the top, of course the magnetizing current curve is just so much sharper. And the contrary, I suppose would also be true. I would like also to say a word for the benefit of those that have probably not seen Dr Somner's paper, that I think appeared in the proceedings of the Royal Society about two years ago. A method is there given by him, by means of which—when you have a complicated case of the primary and the secondary, or merely a primary. or rather, a wire circuit in the presence of a magnetic circuit alone, but which wire has considerable resistance, and therefore in which case the fall of potential does amount to considerable, the problem treated analytically being a very difficult one—you can determine what would happen beforehand. By the method that is there presented the entire matter can be worked out graphically without much trouble. I can give you an idea of what the elemental curves look like, to give a resulting curve that is the same as one that can be produced by one of the ordinary alternators used in this country, in which the drum type of armature is used. (Illustrating by a drawing on the black-board). When you plot in the sine curve of the first order it is always steeper. The second order drops out. Then the next is three, something like that. (Indicating). The fourth, of course, drops out. Then we have five alternations running along, two and a half on this side and two and a half on the other. (Indicating). That is the only analysis of the curve that we have made.

THE PRESIDENT:—I notice that in Mr. Powell's paper he speaks of obtaining the mean current in a number of cases, as the square root of the mean square of the instantaneous currents throughout the curve. I should like to know if he has made any investigation of the application of that method to such irregular curves as are shown here in a number of cases, where the curve is nothing like a sine curve.

MR. POWELL:—The only cases in which we use the square of the mean square, were in cases of the secondary electromotive force and secondary current. The resistance being known, the secondary current would be a function of the secondary electromotive force. We did not have any method of determining the values of the secondary current except in that manner. We measured the secondary current by an electro dynamometer, and assumed that that was the mean square, as this curve is very

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nearly the sine curve (indicating). In all cases in the primary circuit we determined the watt curves, as shown in plate 7, and then found the mean watt ordinate.

PROF. RYAN:—An interesting case for such a comparison would have been Fig. 13, but I am sorry to report that we did not make such comparison in the observation. In some work that we did last summer we always found with the instruments, that they compared within one or two per cent. with the square root of the mean square determined from the diagram.

Adjourned.

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# AMERICAN INSTITUTE OF ELECTRICAL ENGINEER.

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| FARMER, PROF. MOSES G. | Electrician and Inventor, Eliot, Me. | A April 15, 1884<br>H.M. Oct. 21, '90 |
| GREEN, DR. NORVIN | (*Past President*). Pres't Western Union Telegraph Co. P. O. Box 3393, 195 Broadway, New York. | A April 15, 1884<br>M Oct. 21, 1884<br>H.M. Dec. 3, 1889 |

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| BATCHELLER, B. C. | Superintendent of the Pneumatic Dynamite Gun Co., 71 Broadway, New York. | A Sept. 6, 1887<br>M Nov. 1, 1887 |
| BATCHELOR, CHAS. | Electrical Engineer, 33 West Twenty-fifth St., New York. | A June 8, 1887<br>M July 12, 1887 |
| BATES, J. H. | Box 2702, New York. | A Sept. 6, 1887<br>M Oct. 1, 1889 |
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| BELL, PROF. A. GRAHAM | 1336 Nineteenth St., Washington, D. C. | A April 15, 1884<br>M Oct. 21, 1884 |
| BELL, DR. LOUIS, | Editor *Electrical World*, 167 Times Building, P.O. Box 3332, N. Y. | A May 20, 1890<br>M June 17, 1890 |
| BERNARD, EDGAR G. | Electrical Engineer, Genesee House, Utica, N. Y. | A Jan. 5, 1886<br>M July 12, 1887 |
| BIRDSALL, E. T. *M. E.* | Electrical Engineer, 115 Broadway, New York. | A June 8, 1887<br>M Nov. 1, 1887 |

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| Name. | Address. | Date of Membership. |
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| BLAKE, EDWARD | Treasurer of New England Electric Co., 55 Oliver St., Boston, Mass. | A May 24, 1887<br>M Sept. 3, 1889 |
| BLAKE, FRANCIS | Auburndale, Mass. | A Sept. 3, 1889<br>M Oct. 1, 1889 |
| BLODGETT, GEO. W. | Electrical Engineer B. & A. R. R. and Consulting Electrician, Boston, Mass. | A July 12, 1887<br>M Sept. 6, 1887 |
| BOSCH, ADAM | Sup't, Fire Alarm Telegraph, Newark, N. J. | A April 15, 1884<br>M Jan. 6, 1885 |
| BRADLEY, CHAS. S. | Electrical Engineer, Yonkers, N. Y. | A May 24, 1887<br>M Dec. 6, 1887 |
| BROOKS, MORGAN | Secretary and Treasurer, The Electrical Engineering & Supply Co., 413 Jackson St., and 529 Holly Ave., St. Paul, Minn. | A May 20, 1890<br>M June 17, 1890 |
| BROWN, JO. STANFORD | Electrical Engineer, with United Electric Traction Co. 115 Broadway, New York. | A Sept. 6, 1887<br>M Nov. 1, 1887 |
| BRUSH, CHAS. F. | Electrical Engineer, 956 Euclid Ave, Cleveland, O. | A April 15, 1884<br>M Oct. 21, 1884 |
| BYLLESBY, HENRY M. | Vice-President and Gen'l Manager, Westinghouse Electric Co., Pittsburgh, Pa. | A Sept. 7, 1888<br>M Oct. 2, 1888 |
| CARROLL, LEIGH | President and General Manager, The Edison Electric Illuminating Co., Birmingham, Ala. | A Oct. 1, 1889<br>M Nov. 12, 1889 |
| CHAMBERLAIN, J. C. | (*Manager.*) Supt. Julien Electric Traction Co , 135 East 18th St., New York. | A Dec. 6, 1887<br>M Jan. 3, 1888 |
| CHEEVER, CHAS. A. | 13 Park Row, New York. | A April 15, 1884<br>M Oct. 21, 1884 |
| CHURCH, WM. LEE | Member of Westinghouse, Church, Kerr & Co., Engineers, 620 Atlantic Ave., Boston, Mass. | A April 5, 1887<br>M May 17, 1887 |
| CLARK, ERNEST P. | Electrical Engineer, 192 Broadway, New York. | A Jan. 8, 1887<br>M Nov. 1, 1887 |
| CLARKE, CHAS. L. | Mechanical and Electrical Engineer, 55 Liberty St., New York. | A April 15, 1884<br>M Jan. 6, 1885 |
| COLBY, EDWARD A. | Electrician of the Weston Electrical Instrument Co., 606 High St., Newark, N. J. | A April 2, 1889<br>M May 7, 1889 |
| CONANT, THOMAS P. | District Engineer, Edison General Electric Co., Edison Building, Broad St., Box 3067, New York. | A Nov. 1, 1887<br>M Jan. 3, 1888 |
| CONDICT, G. HERBERT | General Manager, The Electric Car Co. of America, 4720 Green St., Germantown, Pa. | A July 12, 1887<br>M Sept. 6, 1887 |
| COTHREN, WM. H. | Sup't of Wiring Department, Edison Electric Illuminating Co., 432 Fifth Ave., New York. | A Aug. 6, 1889<br>M Oct. 1, 1889 |
| COWLES, ALFRED H. | Technical Adviser to the Cowles Smelting and Aluminum Co., Lockport, N. Y. | A Mar. 5, 1889<br>M May 7, 1889 |
| CROCKER, FRANCIS B. | (*Vice-President.*) Instructor in Electrical Engineering, School of Mines. Columbia College, and 54 W. 21st Street, New York. | A May 24, 1887<br>M April 2, 1889 |

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| Name. | Address. | Date of Membership. |
|---|---|---|
| CROSS, PROF. CHAS. R. | Thayer Professor of Physics, and Director of the Rogers Laboratory, Mass. Institute of Technology, Boston, Mass. | A April 15, 1884<br>M Oct. 21, 1884 |
| CUTTRISS, CHAS. | (*Manager*). Electrician, The Commercial Cable Co., 1 Broad St., New York. | A Nov. 1, 1887<br>M Dec. 6, 1887 |
| DAFT, LEO | Electrician, Plainfield, N. J. | A Dec. 9. 1884<br>M Jan. 6, 1885 |
| DANVERS, ALAN | Managing Director and Chief Electrician, The Anglo-Portugese Telephone Co., L't'd. 60 Travessa Santa Justa, Lisbon, Port'l. | A Nov. 1, 1887<br>M Sept. 3, 1889 |
| DANVERS, ERNESTO | Electrical Engineer, Casilla 74, Rosario, Argentine Republic. | A Jan. 3, 1888<br>M May 1, 1888 |
| DAVIES, JOHN E | Professor of Physics, University of Wisconsin, 523 Carroll St. Madison, Wis | A Jan. 7, 1890<br>M Mar. 18, 1890 |
| DAVIS, CHARLES H. | Consulting Electrical Engineer, 120 Broadway, New York. | A Mar. 18, 1890<br>M June 17, 1890 |
| DELAFIELD, A. FLOYD, | *Ph.D.* Electrical Engineer, Noroton, Conn. | A May 7, 1889<br>M Oct. 1, 1889 |
| DICKENSON, SAMUEL S. | Sup't, Commercial Cable Co., Hazel-Hill, Guysborough Co., N.S. | A Mar. 6, 1888<br>M Oct. 1, 1889 |
| DIEHL, PHILIP | Inventor, Singer Sewing Machine Co., Elizabeth, N. J. | A April 15, 1884<br>M Dec. 9, 1884 |
| D'INFREVILLE, GEORGES | Electrical Engineer and Expert 110 Liberty St., New York. | A Nov. 1, 1887<br>M Dec. 6, 1887 |
| DOIJER, H. | Care of J. G. F. Rooker, W. I. Vostringel, Delft, Holland. | A Jan. 7, 1890<br>M Mar. 18, 1890 |
| DUDLEY, CHARLES B. | Chemist and Scientific Expert, Penn. R. R. Co, 1219 Twelfth Ave., Altoona. Pa. | A Oct. 1, 1889<br>M Nov. 12, 1889 |
| DUNCAN, DR. LOUIS | (*Vice-President*). Johns Hopkins University, Baltimore, Md. | A July 12, 1887<br>M Sept. 6, 1887 |
| DYER, R. N. | Patent Attorney, 40 Wall St., New York. | A July 12, 1887<br>M Sept. 6, 1887 |
| EDISON, THOMAS A. | Electrician and Inventor, Orange, N. J. | A April 15, 1884<br>M Oct. 21, 1884 |
| FARNHAM, ISAIAH H. | Electrician for the N. E. Telephone & Telegraph Co., 50 Pearl St., Boston, Mass. | A June 8, 1887<br>M July 12, 1887 |
| FIELD, C. J. | President and General Manager Field Engineering Co., 15 Cortlandt St., New York. | A June 8, 1887<br>M Nov. 1, 1887 |
| FIELD, STEPHEN D. | Electrician and Inventor, Stockbridge, Mass. | A April 15, 1884<br>M Oct. 21, 1884 |
| FITCH, D. H. | President, The Fitch Battery and Electric Co., Oneida, N. Y. | A Sept. 3, 1889<br>M Oct. 1, 1889 |
| FLEMING, WILFRID H. | Care of Howard Fleming, Park Ave., Plainfield, N. J. | A Dec. 6, 1887<br>M Jan. 3, 1888 |
| FOSTER, HORATIO A. | (*Manager.*) Electrical Engineer, 45 E. Twenty-second St., New York. | A June 8, 1887<br>M Sept. 6, 1887 |
| FREEMAN, DR. FRANK L. | Attorney-at-Law, Solicitor of Patents, Electrical Expert, 931 F St., Washington, D. C. | A May 7, 1889<br>M Sept. 3, 1889 |

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| Name. | Address. | Date of Membership. |
|---|---|---|
| GARRATT, ALLAN V. | Care Electric Club, 17 East 22d Street, New York. | A April 2, 1889<br>M May 7, 1889 |
| GARVER, M. M. | 48 Walnut St., Newark, N. J. | A July 10. 1888<br>M Sept. 3, 1889 |
| GEYER, DR. WM. E. | (*Manager*). Stevens Institute of Technology, Hoboken. N. J. | A June 5, 1888<br>M Sept. 7, 1888 |
| GRISCOM, WM. W. | Haverford College P. O., Montgomery Co., Pa. President, The Electro Dynamic Co., 224 Carter St., Philadelphia and Managing Electrician The Electrical Accumulator Co., New York. | A June 5, 1888<br>M Mar. 18, 1890 |
| HALL, CLAYTON C. | Civil Engineer, 810 Park Ave., Baltimore, Md. | A April 15, 1884<br>M Oct. 21, 1884 |
| HAMBLET, JAMES | Manager Time Service, W. U. Tel. Co., 195 Broadway, P. O. Box 3393. New York. | A Nov. 1, 1887<br>M Dec 6. 1887 |
| HAMILTON, GEO. A. | Electrician, Western Electric Co., 22 Thames cor. Greenwich St., New York. | A April 15. 1884<br>M Oct. 21, 1884 |
| HAMMER, W. J. | Consulting and Supervising Electrical Engineer, 533 Temple Court, N. Y., and 23 Rowland St, Newark, N. J. | A June 8, 1887<br>M July 12, 1887 |
| HANCOCK, WM. J. | Supt. of Telephones, Dept. of Public Works, Perth, Western Australia. | A Jan. 7, 1890<br>M Mar. 18, 1890 |
| † | | |
| HASKINS, CHARLES H. | Electrician, care of New York Club, Fifth Ave and Thirty-fifth St., New York. | A April 15, 1884<br>M Oct, 21, 1884 |
| HAYES, HAMMOND V. | Electrician, American Bell Telephone Co., Boston, Mass. 127 Purchase St., Cambridge, Mass. | A Nov. 12, 1889<br>M Mar. 18, 1890 |
| HAYNES, F. T. J. | Divisional Telegraph Engineer, Great Western Railway, Taunton. Eng. | A Dec. 6, 1888<br>M Jan. 3, 1887 |
| HAZARD, COL. ROWLAND R. | N. Y. District Railway Co., 120 Broadway, New York. | A April 15, 1884<br>M Oct. 21, 1884 |
| HERING, CARL | Consulting Electrical Engineer, 3816 Spring Garden St, Philadelphia, Pa | A Jan. 3, 1888<br>M June 5, 1888 |
| HERZOG. DR. F. BENEDICT | (*Manager*) President Herzog Teleseme Co., 30 Broad St., New York. | A May 24, 1887<br>M July 12, 1887 |
| HIGGINS, EDWARD E. | Electrical Engineer, Edison Building, Broad Street, New York. P. O Box 3067, New York City. | A June 8, 1887<br>M July 12, 1887 |
| HOUSTON, PROF. EDWIN J. | 1521 Mt. Vernon St., Philadelphia, Pa. | A April 15, 1884<br>M Oct. 21, 1884 |
| HOWELL, JOHN W. | Electrician, Edison Lamp Co., Harrison N. J. | A July 12, 1887<br>M June 5, 1888 |
| HOWELL, WILSON S. | Electrical Expert. Central Station, Edison Elec. Light Sysem, New Brunswick, N. J. | A Sept. 3, 1889<br>M Mar. 18, 1890 |
| HUNTER, RUDOLPH M. | Mechanical and Elect'al Engineer, 926 Walnut St., Philadelphia, Pa | A July 13, 1886<br>M May 17, 1887 |
| HYDE, JEROME W. | Springfield, Mass. | A June 8, 1887<br>M Nov. 1, 1887 |
| JACKSON, DUGALD C. | District Engineer, Edison General Electric Co., Rialto Building, Chicago. Ill. | A May 3, 1887<br>M June 17, 1890 |

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| Name. | Address. | Date of Membership. |
|---|---|---|
| JACKSON, FRANCIS E. | With Edison Lamp Co, Harrison, N. J. | A Jan. 3, 1888<br>M June 17, 1890 |
| JANNUS, FRANKLAND | Solicitor of Patents, 928-30 F. St Washington. D C. | A Nov. 12, 1889<br>M Mar. 18, 1890 |
| JENKS, W. J. | Technical Department, Edison, General Electric Co., 44 Wall Street, New York. | A June 8, 1887<br>M Nov. 1, 1887 |
| JOHNSON, E. H. | President, Interior Conduit and Insulation Co., 16 Broad St., New York. | A Feb. 7, 1888<br>M May 1, 1888 |
| JONES, FRANCIS W. | Assistant Gen'l-Manager and Electrician, Postal-Telegraph Cable Co., 5 Dey St., New York. | A April 15, 1884<br>M Oct. 21, 1884 |
| KNOWLES, E. R. | Civil, Electrical, and Mechanical Engieeer, 181 Broadway, N. Y. and 439*a* Waverly Ave., Brooklyn, N. Y. | A June 8, 1887<br>M July 12, 1887 |
| KNUDSON, A. A. | Electrican, 39 Nassau St., New York. | A Dec. 6. 1887<br>M Jan. 3, 1888 |
| LANGE, PHILIP A. | Superintendent of Detail Department, Westinghouse Electric Co., Pittsburgh, Pa. | A Mar. 6, 1888<br>M June 5, 1888 |
| LANGTON, JOHN | General Manager, Canadian Edison M'f'g Co., Sherbrooke, P. Q. | A Mar. 6, 1888<br>M June 5, 1888 |
| LATTIG, J. W. | Sup't Telegraph, Lehigh Valley R. R., South Bethlehem, Pa | A June 8, 1887<br>M July 12, 1887 |
| LAWSON, A. J. | Electrical Engineer and Contractor, Montreal, P. Q, Box 1009 | A Mar. 18, 1890<br>M June 17, 1890 |
| LEONARD, H. WARD | (*Manager*). General Manager, Edison General Electric Co, P. O. Box 3067, New York. | A July 12, 1887<br>M Sept. 6, 1887 |
| LEONARD. M. B. | Electrical Engineer, and Supt. of Telegraph, Chesapeake & Ohio R'y. Co, Richmond, Va. | A Nov. 6, 1886<br>M May 1, 1888 |
| LIEB, JOHN W, JR. | Chief Engineer, Società Generale Italiana di Elettricita (Sistema Edison). Via S Radigonda N. 4, Milan, Italy. | A Sept. 6, 1887<br>M Nov. 1, 1887 |
| LOCKWOOD, THOMAS D. | (*Manager*). Electrical Engineer. and Advisory Electrician. P. O., Drawer 2. Boston, Mass. | A April 15, 1884<br>M Oct. 21, 1884 |
| LYNE, LEWIS F. | Mechanical and Elect'al Engineer, 307 Grove St., Jersey City, N. J. | A Jan. 3, 1888<br>M June 5, 1888 |
| MAILLOUX, C. O. | Consulting Electrical Engineer, 32 Liberty St., New York. | A April 15, 1884<br>M Oct. 21, 1884 |
| MARKS, WILLIAM DENNIS, | *Ph. B., C. E.* Edison Electric Light Co., Philadelphia, Pa. | A Feb. 7, 1888<br>M May 1, 1888 |
| MARSHALL, J. T. | Inspector of Lamp Manufacture, Edison Lamp Co., Harrison, N. J. | A Oct. 1, 1889<br>M Nov. 12, 1889 |
| MAYNARD, GEO. C. | Electrical Engineer, 1409 New York Ave., Washington, D. C. | A April 15, 1884<br>M Dec. 9, 1888 |
| MILLIS, JOHN | Lieutenant of Engineers, U. S. Army, P.O. Drawer 432. New Orleans, La. | A July 7, 1884<br>M Mar. 3, 1885 |
| MILLS, FRANK P. | Superintendent Cleveland Iron Mining Co., Ishpeming, Mich. | A Jan. 6, 1885<br>M Mar. 3, 1885 |

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| Name. | Address. | Date of Membership. |
|---|---|---|
| NICHOLS, EDWARD L. | (*Vice-President*). Professor of Physics at Cornell University, Ithaca, N. Y. | A Oct. 4, 1887<br>M Dec. 6, 1887 |
| PAINE, SIDNEY B. | Electrical Constructor, member of firm "Paine & Francis," 38 Pearl St., Boston, Mass. | A June 8, 1887<br>M Nov. 1, 1887 |
| PARKS, C WELLMAN | Electrician, 1825 Fifth Ave., Troy, N. Y | A July 12, 1887<br>M May 1, 1888 |
| PARSHALL, H. F. | Electrician, 7 N. Calvert Street, Baltimore, Md. | A Sept. 7, 1888<br>M Mar. 18, 1890 |
| PATTEN, F. JARVIS. | Electrical Engineer, 47 Barclay St., Residence, 10 West Thirtieth St., New York. | A Sept. 6, 1887<br>M Nov. 1, 1888 |
| PFANNKUCHE, GUSTAV | Engineer and Inventor, Cleveland, O. | A Feb. 7, 1888<br>M May 1, 1888 |
| PICKERNELL, F. A. | Sup't. of Equipment, Amer. Tel. & Tel. Co., 18 Cortlandt St. N. Y. | A Feb. 7, 1890<br>M Mar. 18, 1890 |
| POPE, FRANKLIN L. | (*Past President*). Consulting Electrical Engineer and Expert, 15 Wall St., N. Y. Residence, Elizabeth, N. J. | A April 15, 1884<br>M Oct. 21, 1884 |
| PORTER, J. F. | 403 N. 8th Street, St. Louis, Mo. | A Sept. 6, 1887<br>M Nov. 1, 1887 |
| PRATT, J. HOWARD, JR. | Professor of Physics, Milwaukee Acad., Milwaukee, Wis. | A June 5, 1888<br>M Sept. 7, 1888 |
| PRATT, ROBERT J. | Electrician. Manager, Electric M'f'g Co., Troy, N. Y. | A July 12, 1887<br>M Sept. 6, 1887 |
| PRESCOTT, GEO. B., JR | (*Manager*). Electrical Engineer, General Agent, Day's Kerite Wire and Cables. 16 Dey Street. New York. | A July 12, 1887<br>M Nov. 1, 1887 |
| RAYMOND, CHAS. W.<br>* | Civil and Electrical Engineer, Merrimac Consolidated Mining Co., Platoro, Conejos Co., Col. | A June 8, 1887<br>M May 17, 1887 |
| RECKENZAUN, ANTHONY | Electrical Engineer, 7 Albert Terrace, Hemberton Road, Stockwell, London, S. W. England. | A Nov. 1, 1887<br>M Dec. 6, 1887 |
| RECKENZAUN, FREDERICK, | Electrician, Box 225, West Hoboken, N. J. | A Mar. 6, 1888<br>M June 5, 1888 |
| RICE, E. WILBUR, JR. | General Superintendent and Consulting Electrician, Thomson-Houston Elec. Co., Lynn, Mass | A Dec. 6, 1887<br>M Jan. 3, 1888 |
| RIES, ELIAS E. | Electrician and Electrical Engineer, 430 South Broadway, Baltimore, Md. | A July 12, 1887<br>M Sept. 6, 1887 |
| ROBERTS, E. P. | Electrician and Sup't, Swan Lamp Co., Belden St., Cleveland, O. | A Jan. 6, 1885<br>M Feb. 3, 1885 |
| ROHRER, ALBERT L. | Electrical Engineer, with Thomson-Houston Electric Co., Lynn, Mass. | A Nov. 1, 1887<br>M May 1, 1888 |
| SALOMONS, *Sir* DAVID LIONEL, *Bart. M. A.*. | Engineer and Barrister, Broomhill, Tunbridge Wells, Kent and 49 Grosvenor St., London, W., England. | A Feb. 7, 1888<br>M May 1, 1888 |
| SCHLESINGER, WM. M.<br>** | Electrician of Schlesinger, Kimball & Co., Manufacturers of Electric Mining Machinery, 228 West Broad St., Columbus, O. | A Nov. 1, 1887<br>M Dec. 6, 1887 |

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| Name. | Address. | Date of Membership. |
|---|---|---|
| SCHULZE-BERGE, FRANZ | Edison Laboratory, Orange, N. J. | A Nov. 12, 1889<br>M Mar. 18, 1890 |
| SHALLENBERGER, O. B. | Electrician, Westinghouse Electric Co., Pittsburgh, Pa. | A Sept. 7, 1888<br>M Dec. 4, 1888 |
| SHEPARD, WM. E. | Electrician, The Cincinnati Inclined Plane Railway Co., Cincinnati, O. | A Feb. 7, 1890<br>M Mar. 18, 1890 |
| SLATER, HENRY B. | Electrical Engineer and Electro Metallurgist, 1804 California Street, Denver. | A April 15, 1884<br>M Dec. 9. 1884 |
| SMITH, HERBERT G.<br>* | General Electrician, Quezaltenango, Guatémala. | A Mar. 6, 1888<br>M June 5, 1888 |
| STANDFORD, WILLIAM<br>* | Ass't Sup't Telegraphs, Colonial Gov't, Cape Town, Cape of Good Hope, Africa. | A Oct. 4, 1887<br>M Dec. 6, 1887 |
| STEBBINS, THEODORE | Electric Railway Inspector, Thomson-Houston Elec. Co, 620 Atlantic Ave., Boston, Mass. | A July 9, 1889<br>M June 17, 1890 |
| STIERINGER, LUTHER | Electrical Expert, 44 Wall St., Room 71, New York. | A June 8, 1887<br>M Nov, 1, 1887 |
| TERRY, CHARLES A. | Lawyer, Westinghouse Electric Co, Pittsburgh, Pa. | A April 5, 1887<br>M May 17, 1887 |
| THOMPSON, EDWARD P. | Consulting Electrician and Patent Attorney in Electrical Cases, 5 Beekman St., New York. | A April 15, 1884<br>M Dec. 3, 1889 |
| THURNAUER, ERNST | Chief Engineer, Thomson-Houston International Elec. Co., Michaelisbrücke, 1, Hamburg, Germany | A Oct. 14, 1887<br>M Dec. 6, 1887 |
| TROWBRIDGE, PROF. W. P. | School of Mines, Columbia College, New York. | A April 15, 1884<br>M Oct. 21, 1884 |
| TURNER, WILLIAM S. | Electrical Engineer, Woodbridge & Turner, 74 Cortlandt St., New York. | A Dec. 7, 1886<br>M Oct. 2, 1888 |
| VAIL, J. H. | Ass't Engineer in Chief, Edison General Electric Co., Edison Building, P. O. Box 3067, N. Y. | A June 8 1887<br>M Nov. 1, 1887 |
| VAN DEPOELE, CHARLES J. | Electrician, Electrical Railway Department, Thomson-Houston Electric Co., Lynn, Mass. | A June 5, 1888<br>M Sept. 7, 1888 |
| VANSIZE, WILLIAM B | Solicitor of Patents, 44 Broadway, New York. | A April 15, 1884<br>M Oct. 21, 1884 |
| WADDELL, MONTGOMERY | Engineer, 18 Columbia Heights, Brooklyn, N Y. | A Feb. 7, 1888<br>M May 1, 1888 |
| WALKER, SYDNEY F. | Electrical Engineer, 195 Severn Road. Cardiff, England. | A June 2, 1885<br>M May 17, 1887 |
| WALDO, DR. LEONARD<br>* | Electrical Engineer, The Aluminum Brass & Bronze Co., Bridgeport, Conn. | A June 5, 1888<br>M Dec. 4, 1888 |
| WEAVER, W. D. | U. S. N., 144 Henry St. Brooklyn, N. Y. | A May 17, 1887<br>M May 17, 1887 |
| WEEKS, EDWIN R. | General Manager, Kansas City Electric Light Co, National Bank of Kansas City Building. Kansas City, Mo. | A Sept. 6, 1887<br>M Nov. 1, 1887 |
| WESTON, EDWARD | (*Past President* and *Vice-President*) Electrician, 645 High St., Newark, N. J. | A April 15, 1884<br>M Oct. 21, 1884 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| WETZLER, JOSEPH | (*Vice-President.*) Editor *Electrical Engineer*, 150 Broadway, N. Y. | A April 15, 1884<br>M Dec. 9, 1884 |
| WHARTON, CHAS. J. | 82 Bond St., London England. | A Jan. 3, 1888<br>M May 1, 1888 |
| WHEELER, SCHUYLER S., *Sc.D.* | (*Vice-President*). President Crocker-Wheeler Electric Motor Co., 430-432 West Fourteenth St, Electrical Expert, Board of Electrical Control, 1266 Broadway, New York. | A June 2, 1885<br>M Sept. 1, 1885 |
| WILKES, GILBERT | Edison General Electric Co., Edison Building, Box 3067, N. Y. City. | A Jan. 7, 1890<br>M Mar. 18, 1890 |
| WILSON, FREMONT * | Electrician, 293 Lenox (6) Ave., New York. | A Mar. 6, 1888<br>M June 5, 1888 |
| WINCHESTER, A. E. | Designer of Steam Electrical Plants. Wilton, Conn. | A June 8, 1887<br>M Nov. 1, 1887 |
| WOODBRIDGE, J. L. | Electrical Engineer, Woodbridge & Turner, 74 Cortlandt St., New York. | A June 8, 1887<br>M Nov. 1, 1887 |
| ZETSCHE, DR. CARL EDUARD, | Telegraph Engineer, Carlstrasse 8, II Dresden, N Saxony. | A Nov. 1, 1887<br>M Jan. 3, 1888 |

Members, - - - 151.

## ASSOCIATE MEMBERS.

| Name. | Address. | Date of Election. |
|---|---|---|
| ABERNETHY, J. P. | Superintendent of Telegraph, 53 City Hall, Cleveland, O. | July 7, 1884 |
| ABBOTT, ARTHUR V. | Mechanical Engineer, United Electric Traction Co., Closter, N. J. | Oct. 21, 1890 |
| ANDERSON, ALEXANDER * | Superintendent and Manager of the Thomson-Houston Electric Co., Norfolk, Va | Sept. 6, 1887 |
| ANDREWS, WM. S. | Supt Construction Dept, Edison General Electric Co., Edison Building, Box 3067, New York. | Mar. 5, 1889 |
| ATWOOD, GEORGE F. | Edison Laboratory. Orange, N J. | Sept. 16, 1890 |
| BACKSTROM, CHAS. A. | Manufacturer of Electric Incandescent Lamps. 154 & 156 West Twenty-seventh St. New York. | Nov. 13, 1888 |
| BAILLARD, E. V. | 124 West Sixty-first St, New York. | Dec. 3, 1889 |
| BARTON, ENOS M. | President Western Electric Co., 227 South Clinton St., Chicago, Ill. | July 12, 1887 |
| BARRETT, JOHN A. | Electrician, 189 Montague St, Brooklyn, N. Y. | June 8, 1887 |
| BATES, D. H. | Vice-President and Gen'l Manager, The Electrical Accumulator Co., 44 Broadway, New York. | April 15, 1884 |
| BAUER, A. H. | Electrical Engineer, Pullman Palace Car Co., Pullman Building, Chicago, Ill. Room 307. | Feb. 7, 1890 |
| BAUER, W. F. | Constructionist, The Electrical Accumulator Co., 62 Steuben St., East Orange, N. J. | April 15, 1890 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| BAYLES, ROBERT N. | Electrician, The "C & C" Electric Motor Co., 404 Greenwich St., New York. | Oct. 1, 1889 |
| BEATTIE, JOHN, JR. | Manager and Superintendent, The Beattie Battery, Zinc and Electric Co., Fall River, Mass | Sept. 6, 1887 |
| BELDING, WARREN S. | Electrician and Sup't. The Belding Motor and Mfg. Co., 6423 Stewart Boulevard, Englewood, Ill | April 15, 1890 |
| BENBOW, WILLIAM C. | Thomson-Houston Electric Co., 620 Atlantic Ave., Boston, Mass. | Dec. 3, 1889 |
| BENNETT, J. C. | Electrician, United Edison Mfg. Co. 44 Broad St., New York. | Mar. 18, 1890 |
| BERHGOLTZ, HERMAN | General Manager, The Wightman Elec Mfg. Co , 4 Commonwealth Bldg., Scranton, Pa. | April 2, 1889 |
| BERLINER, EMILE | Inventor, Columbia Road, between Fourteenth and Fifteenth Sts., Washington, D C. | April 15, 1884 |
| BINNEY, HAROLD | Assistant in the Practice of Patent Law, with Gilbert M. Plympton, 245 Broadway, New York City. | Sept. 16, 1890 |
| BLACK, CHAS. N. | Student, Princeton Electrical School, Princeton N. J. | Feb. 7, 1890 |
| BLAKE, HENRY W. | Agent, Sprague Electric Railway & Motor Co., 16 Broad St., New York. | Nov. 13, 1888 |
| BLISS, DONALD M. | Electrician The Canada Electric Co., Amherst, N S. | Feb. 7, 1890 |
| BLOOD, W. HENRY, JR. | N. W T. H. E. Co , Pray Building Minneapolis Minn. | April 2, 1889 |
| BOGART, A. LIVINGSTON | Electrical and Patent Expert, 22 Union Square, New York, | July 10, 1888 |
| BOGUE, CHARLES J. | 165 West Eighteenth St., New York, | Dec. 3, 1889 |
| BOTTOMLEY, HARRY | Electrical Engineer, Box 3100, Denver, Col. | April 2. 1889 |
| BOYNTON, EDWARD C. | Care of Elektron M'f'g Co., 79–81 Washington St . Brooklyn, N. Y. | Aug. 6, 1889 |
| BRACKETT, PROF. CYRUS F. | Princeton, N. J. | April 15, 1889 |
| BRADDELL, ALFRED E. | Electrical Inspector, Underwriters' Association. Middle Dep't, 308 Walnut St . Philadelphia, Pa. | Sept. 16, 1890. |
| BRADLEY, FRED. W. | 27 Front St., Schenectady, New York. | May 20, 1890 |
| BRADY, PAUL T. | Superintendent, Central N. Y. Telephone & Telegraph Co., Cooperstown, N. Y. | July 12, 1887 |
| BRINER, C. J. | Vice-President Central Electric Construction Co . 515 Walnut St., St. Louis, Mo. | April 2, 1889 |
| BROPHY, WILLIAM | Chief Inspector, Electric Mutual Insurance Co., 85 Water St., Boston. Residence, 51 Salem St., Worcester, Mass. | Mar. 5, 1889 |
| BROWN, ALEX. S. | Electrical Engineer, Elizabeth, N, J. | Jan. 7, 1890 |
| BROWN, ALFRED S. | Electrical Engineer, Western Union Telegraph Co , 195 Broadway, New York City. | Mar. 18, 1890 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| BROWN, CHARLES A. | Manager Western Electric Co., 227 South Clinton St., Chicago, Ill. | July 12, 1887 |
| BROWNING, HOWARD L. | Promoter and Contractor, 41 Dey St., New York. | Dec. 6, 1887 |
| BUCKINGHAM, CHAS. L. | Patent Attorney, Western Union Telegraph Co., 195 Broadway, P. O Box 3393, New York. | April 15, 1884 |
| BULKLEY, J. NORMAN | Superintendent, U. S. Aluminium Metal Co., Boonton, N. J. | Oct. 21, 1890 |
| BUNCE, THEODORE D., JR. | Battery Expert, The Julien Electric Traction Co., 239 East 27th St., New York City. | May 20, 1890 |
| BURNS, ELMER Z. | Consulting Electrical Engineer, Room 55, 4th Floor. 120 Broadway, N. Y. | Feb. 7, 1890 |
| BUYS, BERT. | Electrician, Rutherford B. S. & C. Elec. Co., Rutherford, N. J. | Feb. 7, 1890 |
| CAHOON, JAS. B. | Electrical Engineer, Thomson-Houston Electric Co., 257 Washington St., Lynn, Mass. | June 17, 1890 |
| CARTY, J. J. | Electrician, Metropolitan Telephone and Telegraph Co., 18 Cortlandt St., New York. | April 15, 1890 |
| CASE, WILLARD E. | 6 Fort St., Auburn, N. Y. | Feb. 7, 1888 |
| CHAMBERLAIN, F. H. | Electrician. Metropolitan R. R. Co., 2411 P St., N. W. Washington, D. C. | June 17, 1890 |
| CHENEY, FREDERICK A. | Sec'y, Treas'r and General Manager, The Elmira Illuminating Co., Elmira, N. Y. | Oct. 1, 1889 |
| CHERMONT, ANTONIO LEITE, | Manager Telephone Co. of Para, Para, U. S. of Brazil, Care Herbst Bros, Box 1377, New York. | Mar. 18, 1890 |
| CHILD, FRANK W. | Contractor and Builder of Electric Railways, 115 Broadway, New York. | July 10, 1888 |
| CHILDS, W. H. | Bookkeeper for The Estey Organ Co., Brattleboro, Vt. | Sept. 6, 1887 |
| CHINNOCK, C. E. | Edison General Electric Co., Edison Building, P. O. Box 3067, New York. | April 15, 1884 |
| CHUBBUCK, H. EUGENE | Electrician and Manager, Champion City Electric Light Co., Springfield, O, | Dec. 4, 1888 |
| CHURCHILL, ARTHUR. | Electrical Expert, Frazar & Co., Yokohama, Japan. | April 15, 1890 |
| CLEVELAND, WM. B. | Electrical Engineer, 309 Perry-Payne Building, Cleveland, O. | April 15, 1884 |
| COBB, JOHN S. | Electrician. Care of Bergmann & Co. Ave. B. and 17th St., New York. | June 17, 1890 |
| COFFIN, CHAS. A. | Vice-President and Treasurer, Thomson-Houston Electric Co., 620 Atlantic Ave , Boston, Mass. | Dec. 6, 1887 |
| COLGATE, GEO. L | Electrical Engineer, Bedford Electric Co., Bedford City, Va. | June 17, 1890 |
| COLLEY, BENJAMIN W. | First Ass't. Superintendent, The Commercial Cable Co, Hazel Hill, N. S. | Oct. 21, 1890 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| COLLINS, W. FORMAN | Western Manager, *The Electrical Engineer*, 225 Dearborn St., Chicago, Ill. | Dec. 6, 1887 |
| ** | | |
| COMPTON, ALFRED G. | Professor of Physics, College of the City of New York, 17 Lexington Ave., New York. | Nov. 1, 1887 |
| CORNELL, CHAS. L. | Electrical Engineer, Western Engineering Co., Hamiton, O. | Feb. 7, 1890 |
| CRANE, W F. D. | Electrician and Mechanical Engineer, The Electric Car Co. of America, 308 S. 10th Street, Philadelphia, Pa. | Feb. 7, 1888 |
| CROSBY, OSCAR T. | Electrical Engineer, Edison General Electric Co., New Orleans, La. | Mar. 18, 1890 |
| CUNTZ, JOHANNES H. | Assistant to Pres't Henry Morton, Stevens Institute of Technology, 137 Hudson St., Hoboken, N. J. | Mar. 5, 1889 |
| CURTIS, CHAS. G. | 114 East Thirtieth St., New York. | April 15, 1884 |
| CURTISS, GEORGE F. | Electrician, Thomson-Houston Electric Co., Lynn, Mass. | April 2, 1889 |
| CUSHMAN, HOLBROOK | Electrical Engineer, 337 West Twenty-second St., New York. | June 5, 1888 |
| CUTTER, GEORGE | Dealer in Electrical Supplies, 192 Fifth Avenue, Chicago, Ills. | June 17, 1890 |
| DANA, R. K. | Agent Washburn and Moen M'f'g Co., 16 Cliff St., New York. | April 15, 1884 |
| DANFORTH, A. H. | Great Falls, Montana. | July 12, 1887 |
| ** | | |
| DANIELL, FRANCIS G. | Care of Minneapolis Street Railway Co., Minneapolis, Minn. | Nov. 12, 1889 |
| DAVENPORT, GEORGE W. | General Manager, Thomson-Houston International Electric Co., 620 Atlantic Ave., Boston, Mass. | June 4, 1889 |
| DAVIDSON, EDW. C. | Patent Lawyer, Room 179, Times Bldg., New York. | Feb. 7, 1890 |
| DAVIS, CHAS. M. | Superintendent, Light, Heat & Power Co., Pueblo, Col. | July 12, 1887 |
| DAVIS, DELAMORE L. | Superintendent, Salem Electric Light & Power Co., Salem, O. | April 2, 1889 |
| DAVIS, JOSEPH P. | Consulting Engineer, Care of Phœnix Construction Co., 115 W. 38th St., New York City. | April 15, 1884 |
| DAVIS, MINOR M. | Ass't Electrician, Postal Telegraph Cable Co., 5 Dey St., New York. | April 6, 1886 |
| DELANY, PATRICK BERNARD, (*Manager*). | Inventor, South Orange, N. J. | April 15, 1884 |
| DENTON, JAMES E. | Professor of Experimental Mechanics, Stevens Institute of Technology, Hoboken, N. J.. | July 12, 1887 |
| DICKERSON, E. N. | Attorney-at-Law, 15 Wall St., N. Y. | April 15, 1884 |
| DION, ALFRED A. | Electrician, Intercolonial Railway, Moncton, N. B. | Jan. 7, 1890 |
| DOANE, S. EVERETT | Thomson-Houston Electric Co., Swampscott, Mass. | Aug. 6, 1889 |
| DOBBIE, ROBERT S. | Electrician, 132 Jackson Ave., Jersey City, N. J. | Feb. 5, 1889 |

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|---|---|---|
| DOREMUS, CHARLES A. | *M. D. Ph. D.* Chemist and Physicist, Bellevue Hospital Medical College, College of the City of New York and American Veterinary College, 92 Lexington Ave , New York. | July 7, 1884 |
| DUNDERDALE, CLEAVELAND F. | Agent Westinghouse Electric Co., 146 Adams St., Chicago, Ill. | June 17, 1890 |
| DURANT, GEO. F. | Vice-Pres't of Bell Telephone Co. of Mo., 322 Pine St., St. Louis, Mo. | April 15, 1884 |
| EKSTROM, AXEL | Electrician, Thomson-Houston Electric Co., Lynn, Mass. | June 17, 1890 |
| ELEY, HARRIS H. | Electrical Workshop Sup't. W. C. & S. W Telephone Co., 88 Colston St., Bristol, Eng. | Jan. 7, 1890 |
| ELMER, WILLIAM, JR. | Under-graduate in Electrical Engineering, Princeton University, Princeton, N. J. | Mar. 18, 1890 |
| EMMET, HERMAN L. R. | Publisher and Printer, 36 Cortlandt St., New York. | April 15, 1884 |
| ENTZ, JUSTUS B. | Electrical Engineer, 18 Columbia Heights, Brooklyn, N. Y. | Jan. 7, 1890 |
| EUSTIS, HERBERT H. | President and Electrician, Eastern Electric Cable Co., 61 Hampshire St., Boston, Mass. | April 15, 1890 |
| FESSENDEN, REGINALD A. | Assistant Electrician, U. S. Electric Light Co., Newark, N. J. | Oct. 21, 1890 |
| FIELDING, FRANK E. | Chemist and Assayer, Virginia City, Nev. | Sept. 6, 1887 |
| FISKE, HENRY G. | Electrician, Croton Magnetic Iron Mines. 45 East Twenty-second Street, New York | Nov. 12, 1889 |
| FISKE, J. P. B. | Electrical Engineer, Thomson-Houston Electric Co., Lynn, Mass. | June 17, 1890 |
| FITCH, GRAHAM D. | First Lieut. Corps of Engineers, U. S A. Duluth, Minn. | Oct. 21, 1890 |
| FLACK, J. DAY | Ass't Electrician in charge of Tests, Edison Lamp Co., Harrison, N. J. | Dec. 6, 1887 |
| FLEMING, WALTER M. *M. D.* * | Vice-President of the Averell Insulating Conduit Co., 45 Broadway, Room 1, New York. | Jan. 3, 1888 |
| FLOOD, J. F. | Electrician, Electric Light & Power Co , Steubenville, O. | Mar. 18, 1890 |
| FORBES, FRANCIS | Lawyer, 137 Broadway. New York City. | Sept. 16, 1890 |
| FORD, ELLSWORTH | Superintendent Edison Electric Light Co., Ottumwa, Ia. | July 12, 1887 |
| FOX, JOHN M. | Electrician, Edison General Electric Co., 133 West 34th Street, N. Y. | Mar. 18, 1890 |
| FRANCISCO, M. J. | President and General Manager, Rutland Electric Light Co., Rutland, Vt. | June 17, 1890 |
| FREEDMAN, WILLIAM H. | Honorary Fellow in Electrical Engineering, Columbia College, 120 West 125th Street, New York. | Mar. 18, 1890 |

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| Name | Address. | Date of Election. |
|---|---|---|
| FULLER, LEVI K. | Vice-President, Estey Organ Co., Brattleboro, Vt. | Mar. 5, 1889 |
| GAINES, J. D. | Second Ass't. Superintendent, The Commercial Cable Co., Hazel Hill. N. S. | Oct. 21, 1890 |
| GILES, WALTER A | Electrical Engineer, Mill and Mine Elec. Equipment Co., 95 Fifth Ave.. Pittsburgh, Pa. | Nov. 1, 1887 |
| GILLILAND, E. T. | Vice-Pres't Empire City Elec. Co., 15 Dey St. Residence, 179 West End Ave., New York. | April 15. 1884 |
| GOLDMARK, CHAS. J. | 473 Park Ave., New York. | June 5, 1888 |
| GORTON, CHARLES | Lock Box 35. Greencastle, Pa. | Nov. 12. 1889 |
| GRAY, W. N. | Manager, Branch Office, Mather Electric Co., Cincinnati, O. | Oct. 1, 1889 |
| GROWER, GEORGE G. | Electrician and Chemist, Ansonia Brass and Copper Co., Ansonia, Conn. | Mar. 18, 1890 |
| GRIFFIN, CAPT. EUGENE | Thomson-Houston Elec. Co., 620 Atlantic Ave., Boston, Mass. | Feb. 7, 1890 |
| GUTMANN, LUDWIG | Electrical Engineer. P. O. Box 560, Pittsburgh, Pa., | Sept 14, 1888 |
| HALL, EDWIN H. | Assistant Professor of Physics, Harvard College, 5 Avon St., Cambridge, Mass. | Sept. 3. 1889 |
| HALL, WILLIAM P. | President, The Hall Signal Co., 50 Broadway. New York City. | Sept. 16. 1890 |
| HARDING, H. McL. | Railway Dep't, Westinghouse Electric Co , Pittsburgh, Pa. | May 24, 1887 |
| HARVEY, WIRT B. * | 43½ Madison St., Memphis, Tenn. | Dec. 6, 1887 |
| HASKINS, CARYL D. | Electrician, Thomson-Houston Electric Co., Lynn, Mass. | Mar. 18, 1890 |
| HASSON, W. F. C. | Assistant Engineer, U. S. N. Instructor Johns Hopkins University. Baltimore, Md. | Mar. 18, 1890 |
| HATZEL, J. C. | Electrical Engineer and Contractor, 29 West Twenty-sixth St., New York. | Sept. 3, 1889 |
| HALSEY, WILLIAM B. | Inspector, Postal Telegraph-Cable Co., 94 Leonard St., New York | Mar. 18, 1890 |
| HEBARD, GEORGE W. | Pres't, United States Electric Light Co., 120 Broadway, New York. | April 15, 1884 |
| HENDERSON, ALBERT H. | Ries and Henderson, 45 Chamber of Commerce, Baltimore, Md. | July 12, 1887 |
| HEILMAN, DONALD B. | Jonestown, Pa. | Mar. 18, 1890 |
| HEINRICH, RICHARD O. | Demonstrator in Electrical Engineering and Physics, Lehigh University, South Bethlehem, Pa. | Oct 1, 1889 |
| HENSHAW, FREDERICK V. | Assistant Electrician, The "C. & C." Electric Motor Co., 402 Greenwich St., New York. | Feb. 5, 1889 |
| HEWITT, CHARLES | Engineering Dep't, Edison General Electric Co., 273 Hicks St., Brooklyn, N. Y. | Sept. 16. 1890 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| HOCHHAUSEN, WILLIAM | Electrician, The Excelsior Electric Co., 196 Willoughby St., Brooklyn, N. Y. | April 15, 1884 |
| HOLCOMB, EUGENE R. | Electrician, Agency Thomson-Houston Electric Co., 234 Montgomery St., San Francisco. Cal. | June 17, 1890 |
| HOLT, MARMADUKE BURRELL, | Aspen Mining and Smelting Co., Aspen, Col. | April 15, 1890 |
| HOPKINS, J. HERBERT | 403 North 8th St., St. Louis, Mo. | April 2, 1889 |
| HOWSON, HUBERT | Patent Lawyer, 38 Park Row, New York. | June 8, 1887 |
| HUBRECHT, DR. H. F. R. | Director, Nederlandsche Bell Telephone Co., Amsterdam, Holland. | Oct. 4, 1887 |
| HUMPHREYS, C. J. R. | Manager, Lawrence Gas Co., Lawrence, Mass. | Sept. 6, 1887 |
| HUTCHINSON, DR. CARY T. | Electrical Engineer, 56 West 25th St., New York City. | Feb. 7, 1890 |
| IDELL, FRANK E. | Mechanical Engineer, 41 Dey St., New York. | July 12, 1887 |
| IHLDER, JOHN D. | Electrical Engineer, with Osterheld & Eickemeyer, Manuf'rs of Dynamos and Motors, Yonkers, N. Y. | Oct. 2, 1888 |
| INSULL, SAMUEL | Electrical Manufacturer, 44 Wall St., New York. | Dec. 7, 1886 |
| ISELIN, HENRY S. | President, Gibson Electric Co., 74 Cortlandt St., New York. | June 2, 1885 |
| IVES, EDWARD B. | Lieutenant U. S. A., Electrical Engineer, 47 Barclay St., Residence, One hundred and thirty-ninth St. and Grand Boulevard, New York. | April 2, 1889 |
| IZARD, E. M. | Electrical Engineer, General Manager, Inter-State Cooling Co, 167 Dearborn St., Chicago, Ill. | Mar. 5, 1889 |
| JACKSON, C. H. | President, United Electric Light and Power Co., 59 Liberty St., New York. | May 24, 1887 |
| JAEGER, H. J. | Chemical, Physical and Electrical Glass Blowing, 173 Pearl St., Brooklyn, N. Y. | July 12, 1887 |
| JOHNSTON, W. J. | President, The W. J. Johnston Co., Ltd., Times Building, P. O. Box 3332, N. Y. | April 15, 1884 |
| JONES, F. R. | University of Tennessee, Knoxville, Tenn. | May 20, 1890 |
| JONES, SEBASTIAN C. ** | Electrical Engineer, Aurora, N. Y. | Sept. 6, 1887 |
| JUDSON, WM. PIERSON, | U. S. Civil Engineer, Oswego, N. Y. | June 8, 1887 |
| KEEN, WILLIAM M. B. | Electrician, The Clark Electric Co., Co., 478 Pearl St., and 410 East 26th Street New York City. | Sept. 16, 1890 |
| KENNELLY, A. E. | Electrician, Edison Laboratory, Orange, N. J. | May 1, 1888 |
| KERR, THOMAS B. | Attorney-at-Law, 120 Broadway New York. | Nov. 1, 1887 |
| KIMBALL, A. S. | Professor of Physics, Worcester Polytechnic Institute, Worcester, Mass. | Sept. 3, 1889 |

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|---|---|---|
| KINNEY, H. A. | Representative Brush Electric Co., N. Y. Life Ins. Building. Omaha, Neb. | Mar. 18, 1890 |
| KNAPP, ALLAN C. * | Electrician, 225 Dearborn St., Chicago, Ill. | Sept. 6, 1887 |
| KNIGHT, WM. B. | Civil Engineer (Specialty, Cable and Electric Railways), 200 West 6th St., Kansas City, Mo. | Sept. 16, 1890 |
| KREIDLER, W. A. | Editor and Publisher, *Western Electrician*, 6 Lakeside Building, Chicago, Ill. | Oct. 4, 1887 |
| LAIN, DAVID E., *B. S.* | Electrical Engineer, Yonkers, N. Y. | Nov. 13, 1888 |
| LAW, M. D. | Sup't and Electrician, Denver Consolidated Electric Co., 1534 Lawrence St., Denver, Col, | Feb. 7, 1888 |
| LEDOUX, A. R. | Chemical Expert, 10 Cedar St., New York. | Dec. 7, 1886 |
| LEE, HUNTINGTON | Pittsfield, Mass. | Dec. 3, 1889 |
| LEE, JOHN C. | Chemist and Electrician, American Bell Telephone Co., Brookline, Mass. | Mar. 18, 1890 |
| LELAND, H. W. *** | Manager, Telephone Exchange, 259 Washington St., Jersey City, N. J. | April 15, 1884 |
| LEMP, HERMANN, JR. | Electrician, Thomson Electric Welding Co., Lynn, Mass. | April 2, 1889 |
| LEWIS, HENRY FREDERICK WILLIAM, | General Manager and Secretary of the Western Counties South Wales Telephone Co., England, 16 High St., Bristol, Eng. | Mar. 5, 1889 |
| LIEBIG, GUSTAV A., JR. | Elec'l Testing Bureau, Johns Hopkins University, Baltimore, Md. | Mar. 6, 1888 |
| LLOYD, ROBERT MCA. | Electrician of the Marion, N. J. Factory, United Electric Traction Traction Co., 2 W. 36th St., New York City. | Oct. 21, 1890 |
| LOOMIS, OSBORN P. | Electrician, Eureka Electric Co., 530 Nostrand Ave., Brooklyn, N.Y. | Sept. 16, 1890 |
| LOWREY, GROSVENOR P. | Lawyer, 15 Broad St., Residence 121 Madison Ave., New York. | Nov. 1, 1887 |
| LOZIER, ROBERT T. E. | Electrical Expert, The Edison United Mfg. Co., 65 Fifth Ave., New York. | May 20, 1890 |
| LUFKIN, HARVEY L. | General Agent, "C & C" Electric Motor Co., 404 Greenwich St., New York. | June 17, 1890 |
| LUNDELL, ROBERT | Designing Draftsman, Sprague Elec. Ry. Co., 141 East 49th St., New York. | Feb. 7, 1890 |
| MACLILIE, C. H. * | Broker in Electrical Securities, 11 Wall St., New York. | July 12, 1887 |
| MAC QUESTEN, W. D. | Electrical Engineer and Contractor, 15 Cortlandt St., New York. | April 15, 1890 |
| MADDEN, O. E. | President, Empire City Electric Co., 15 Dey St., New York. | April 15, 1884 |
| MAGEE, LOUIS J. | Electrical Engineer, in charge of European Office of Thomson-Houston International Electric Co., Michaelisbrücke 1, Hamburg, Gy. | April 2, 1889 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| MALCOLM, PHILIP S. | Western Agent, Gibson Electric Co., Portland, Oregon. | Mar. 18, 1890 |
| MANSFIELD, GEO. W. | Electrical Engineer, with Thomson-Houston Electric Co., 620 Atlantic Ave., Boston, Mass. | June 2, 1885 |
| MARKS, LOUIS B. | Graduate Student, 51 East 67th St., N. Y. | May 20, 1890 |
| MARTIN, F. | Inspector of Isolated Plants, Edison Electric Illuminating Co., of N. Y., 16 Oak St., Newark, N. J. | Oct. 21, 1890 |
| MARTIN, J. | Electrician, Hanson, Van Winkle & Co., 16 Oak St., Newark, N. J. | Oct. 21, 1890 |
| MARTIN, T. COMMERFORD | (*Past President.*) Editor, *The Electrical Engineer*, 150 Broadway, New York. | April 15, 1884 |
| MASON, AUGUSTE F. | General Manager, Simplex Electric Co., 620 Atlantic Avenue, Boston, Mass. | June 17, 1890 |
| MAVER, WILLIAM, JR. | (*Manager.*) Electrical Expert, 31 Nassau St., New York. | July 12, 1887 |
| MCCAY, H. K. | Electrician, Consolidated Electric Co. Amsterdam, N. Y. | Sept. 16, 1890 |
| MCKIBBIN, GEORGE N. | Chemist and Electrician, 46 West Fifty-first St., New York. | June 8, 1887 |
| MCKINSTRY, J. P. | 185 Seneca St., Cleveland, O. | April 15, 1884 |
| †MCMAHAN, JOHN M. | Bergen Point, N. J. | Aug. 6, 1889 |
| †MERCER, ANDREW G. | Treasurer and Electrician, Waterloo Electric Co., Waterloo, N. Y. | Sept. 3, 1889 |
| MERRITT, ERNEST | Instructor in Physics, Cornell University, Ithaca, N. Y. | Sept. 16, 1890 |
| MILLER, JOSEPH A. | Civil and Consulting Engineer, Providence, R. I. | Dec. 9, 1884 |
| MILLER, WM. C. | General Manager, Watervliet Turnpike & R. R. Co., 3 South Hawk Street, Albany, N. Y. | Oct. 21, 1890 |
| MINER, W. M. | Electrician and Inventor, 89 East Second St., Plainfield, N. J. | July 12, 1887 |
| MITCHELL, JOHN MURRAY | Lawyer, Box 3712, 45 Wall St., New York. | June 2, 1885 |
| MITCHELL, SIDNEY Z. | Manager, Oregon, Washington and Idaho Agency, Edison General Electric Co., Washington Building, Portland, Or. | Nov. 12, 1889 |
| MIX, EDGAR W. | Electrician, with Thomson-Houston Electric Co., Lynn, Mass. | Sept. 3, 1889 |
| MOORE, JOHN J. | 425 E. Twenty-fourth St., New York. | Nov. 12, 1889 |
| MORRISON, J. FRANK | 15 South St., Baltimore, Md. | April 15, 1884 |
| MORTON, HENRY, *Ph. D* | President of Stevens Institute of Technology, Hoboken, N. J. | May 24, 1887 |
| MOSES, DR. OTTO A. | Electrician, 131 East Seventy-third St., New York. | May 17, 1887 |
| MOSS, GEO. W. | Station Manager, C. & S. A. Tel. Co., Tehuantepec, Mexico. | Jan. 7, 1890 |
| MOSSCROP, WM. A. | Sup't of Construction, Woodbridge & Turner, Amsterdam, N. Y. | May 7, 1889 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| MYERS, GEO. FRANCIS | Post-Graduate Student, Cornell University, 69 Heustis St., Ithaca, N. Y. | June 17, 1890 |
| NESMITH, S. D. | Ohio Agent, Edison General Electric Co., 322 Society for Savings Building, Cleveland, O. | Sept. 16, 1890 |
| NEWELL, ARTHUR J, | Electrical Engineer, R. T. Oakes & Co., 184 Beech St., Holyoke, Mass. | Mar. 18, 1890 |
| NICHOLLS, F. VICTOR * | Electrician and Manager Vancouver Electric Illuminating Co., Vancouver, B. C. | Dec. 4, 1888 |
| NICHOLS, ARTHUR E. | Student in Electrical Engineering, Columbia College, 16 E. 35th St., New York City. | Mar 18, 1890 |
| NUNN, RICHARD J., *M. D.* | Physician, 119 York St., Savannah Ga. | July 12, 1887 |
| OATIS, JOHN X. * | Manager and Electrician, Amsterdam Electric Light & Power Co., Amsterdam, N. Y. | Sept. 7, 1888 |
| OCKERSHAUSEN, H. A. | Electrical Engineer, 65 Madison Ave., Jersey City, N. J. | Sept. 6, 1887 |
| O'DEA, M. | Electrician, University of Notre Dame, Notre Dame, Ind. | June 8, 1887 |
| OWENS, R. B. † | Superintendent, Greenwich Gas and Electric Light Co., Greenwich, Conn. | June 17, 1890 |
| PALMER, G W., JR. | General Manager, McKeesport Light Co., McKeesport, Pa. | April 15, 1890 |
| PARSELL, HENRY V., JR. | 31 East Twenty-first St., New York. | Nov. 12, 1889 |
| PAUL, CHAS. M. | Electrician, Care of Weston Electrical Instrument Co., 645 High St., Newark, N. J. | May 7, 1889 |
| PECK EDWARD F. | General Sup't Citizens Electric Illuminating Co., Cor. Navy St. and DeKalb Ave., Brooklyn, N. Y. | May 20, 1890 |
| PECK, SAMUEL C. | Electrician, Thomson-Houston Electric Co., 620 Atlantic Ave, Boston Mass. | Sept. 6, 1887 |
| PEIRCE, WM. H. | Superintendent Marine Installations, Edison General Electric Co., Edison Building, P. O. Box 3067, New York. | Sept. 7, 1888 |
| PERKINS, FRANK C, | Student in Electrical Engineering, Cornell University, Ithaca, N. Y. | Oct. 21, 1890 |
| PERRINE, FREDERIC A. C. | Superintendent Insulated Wire Dep't. John A. Roebling's Sons Co., 137 E. State St., Trenton, N. J. | Sept. 16, 1890 |
| PHELPS, GEO. M. | (*Treasurer*). President, *Electrical Engineer*, 150 Broadway, New York. | April 15, 1884 |
| PHILLIPS, EUGENE F. | M'f'r Insulated Electric Wire, Providence, R. I. | July 13, 1889 |
| POOLE, CECIL P. | Contracting Electrical Engineer. 206–8 Eighth St. Lynchburg, Va. | Jan. 3, 1888 |
| PUPIN, DR. MICHAEL I. | Instructor in Mathematical Physics. Columbia College, 68 W. 72d St., New York City. | Mar. 18, 1890 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| POPE, RALPH W. | Secretary of the American Institute of Electrical Engineers, Editor *Electric Power*, 12 W. 31st St., New York. Residence 570 Cherry St., Elizabeth, N. J. | June 2, 1885 |
| POWELL, WILLIAM H. | 148 Webster St. Pittsburgh, Pa. | June 17, 1890 |
| PUTNAM, H. ST. CLAIR | Treasurer and Electrician, Thomson-Houston Carbon Co., Fremont, O. | Sept. 16, 1890 |
| RAE, FRANK B. | Electrical Engineer, Detroit Electrical Works, Detroit, Mich. | April 15, 1884 |
| RANDALL, JOHN E. | Incandescent Lamp Dep't, Thomson-Houston Electric Co., Lynn, Mass. | May 7, 1889 |
| REED, CHAS. J. | Electrician, 224 High St., Orange, N. J. | Mar. 5, 1889 |
| REED, HENRY A. | Secretary and Manager, Bishop Gutta-Percha Co., 422 East Twenty-fifth St., New York. | June 4, 1889 |
| REID, THORBURN | Consulting Electrical Engineer and Expert, 15 Wall and 26 E. 33d Sts., New York City. | Oct. 21, 1890 |
| REILLY, JOHN C. | General Sup't, N. Y. & N. J. Tel. Co., 16 Smith St., Brooklyn, N. Y. | April 15, 1884 |
| REINMANN, A. L. | Electrician, Breckenridge Ave., Pittsburgh, Pa. | June 8, 1887 |
| REIST, H. G. | Electrical Engineer, Thomson-Houston Electric Co., 113 Franklin St., Lynn, Mass. | June 17, 1890 |
| RIKER, ANDREW L. | Electrical Engineer, 15 East Fifty-fifth St., New York. | Nov. 1, 1887 |
| ROBINSON, ALMON, | Draughtsman, Expert in Methods of Gearing, P. O. Box, 943, Lewiston, Me. | Sept. 6, 1887 |
| RODMAN, SAMUEL, JR. | Lieut. 1st Artillery, U. S. A., Fort Columbus, N. Y. Harbor. | Sept. 16, 1890 |
| ROEBLING, FERDINAND W. | Manufacturer of Electrical Wires and Cables, Trenton, N. J. | June 8, 1887 |
| ROESSLER, S. W. | Captain, U. S. A., U. S. Engineer Office, Memphis, Tenn. | Dec. 3, 1889 |
| ROGERS, WINFIELD S. | Mechanical Engineer, Estate of F. W. Richardson, Troy, N. Y. | Sept. 3, 1889 |
| ROME, H. C. | 32 Liberty St., New York. | April 15, 1889 |
| ROSENBAUM, WM. A. | Electrical and Patent Solicitor, Care of *The Electrical World*, Times Building, New York. | Jan. 3, 1889 |
| ROSENBERG, E. M. | Supt. Manhattan E. L. Co., 80th St., and Ave. B. Residence, 784 Lexington Ave., N. Y. City. | Oct. 21, 1890 |
| ROYCE, FRED W. | Electrician and Patent Solicitor, 1408 Pennsylvania Ave., Washington D. C. | April 15, 1884 |
| RYAN, HARRIS J. | Professor of Electrical Engineering, Cornell University, Ithaca, N. Y. | Oct. 4, 1887 |
| SARGENT, W. D. | General Manager, N. Y. & N. J. Tel. Co., 16 Smith St., Brooklyn, N. Y. | April 15, 1884 |
| SAWYER, FREDERICK J. | Pres't, The New England Electric Co., 55 Oliver St., Boston, Mass. | June 8, 1887 |

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|---|---|---|
| SAXELBY, FREDERICK, | Electrical Engineer, Superintendent of Exhausting Department, Edison Lamp Co., Harrison, N. J. | June 5, 1888. |
| SCHMID, ALBERT | Superintendent, Westinghouse Electric & Mfg. Co., Pittsburgh, Pa. | Oct. 21, 1890. |
| SCHMIDT, FREDERICK, | Managing Director, The Schmidt-Douglas Electric Co., L'td., 31 Blenheim Rd., Bradford, England. | Jan. 3, 1888 |
| SEARING, LEWIS | Care A. S. Pope, Box 124. Colorado Springs, Colorado. | April 3, 1888 |
| SEELY, J. A. | General Manager, Complete Construction Co., 24 Cortlandt St., New York. | April 15, 1884 |
| SERRELL, LEMUEL WM. | Mechanical and Electrical Engineer, 115 Broadway, New York. | Nov. 1, 1887 |
| SHAW, GEORGE B. | General Manager, National Electric Mfg. Co., Eau Claire, Wis. | April 15, 1890 |
| SHEBLE, FRANKLIN | Electrical Engineer, Thomson-Houston Electric Co., Lynn, Mass. | Oct. 21, 1890 |
| SHEEHAN, WILLIAM M. | Manager and Electrician, Newburgh Electric Light & Power Co., 65 Montgomery St., Newburgh, N.Y. | Sept. 3, 1889 |
| SINCLAIR, H. A. | Electrical Engineer. The Tucker Electric Co., 950 Bedford Ave., Brooklyn, N. Y. | June 17, 1890 |
| SISE, CHARLES F. | Vice-President and Managing Director, Bell Telephone Co., of Canada, and Canadian Telephone Co., Ltd., Montreal, Canada. | June 8, 1887 |
| SMITH, FREDERICK H. | Civil Engineer. 227 East German St., Baltimore, Md. | Nov. 12, 1889 |
| SMITH, GERRITT | Circuit Electrician, 195 Broadway, P. O. Box 3393, New York. | April 15, 1884 |
| SMITH, J. ELLIOT | Superintendent Fire Alarm Telegraph, 157 East Sixty-seventh St., New York. | April 15, 1880 |
| SMITH, JESSE M. | Consulting Electrical Engineer and Expert in Patent Causes, 36 Moffatt Block, Detroit, Mich. | April 15, 1884 |
| SOUZA, CARLOS MONTEIRO e | Rio de Janeiro, Brazil. | Sept. 6, 1887 |
| SPICER, CHAS. W. W. | 122 West 21st. St , New York City. | Nov. 12, 1889 |
| SPIKE, CLARENCE J. | Halifax, N. S | Mar. 18, 1890 |
| SPRAGUE, FRANK J. | (*Vice-President.*) Electrical Engineer and Inventor, 277 West 73d St., New York. | May 24, 1887 |
| STADELMAN, WM. A. | Vice-Prest. and Chief Engineer, Equitable Elec. Ry. Construction Co., 418 Walnut St , Philadelphia, Pa. | Feb. 7, 1890 |
| STANLEY, WILLIAM, JR. | Electrician, Pittsfield, Mass. | Dec. 6, 1887 |
| STEARNS, CHARLES K. | Sup't of Construction, N. W. Thomson-Houston Electric Co., 403 Sibley St., St. Paul, Minn. | Aug. 6, 1889 |
| STEINMETZ, CHARLES | Electrician, Osterheld & Eickemeyer, Yonkers, N. Y. | Mar. 18, 1890 |
| STOCKBRIDGE, GEO. H. | Patent Attorney, and Editor *Electric Power*. 132 Nassau St., New York. | May 24, 1887 |

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| Name. | Address | Date of Election |
|---|---|---|
| STOCKLY, GEO. W. | President, Brush Electric Co., Cleveland, O. | April 15, 1884 |
| STOREY, IMLE E. | Electrician and Manager, Storey Electric Drill and Power Co., 16 Broad St., New York City. | May 20, 1890 |
| † STUART, OTIS K. | Clerk, Thomson Electric Welding Co., Lynn, Mass. | June 4. 1889 |
| STUMP, CLARENCE E. | Bus. M'g'r and Treas'r, The W. J. Johnston Co., Ltd., Publishers of the *Electrical World*, 167 Times Building, P. O. Box 3332, New York. | May 17, 1887 |
| SWEET, HENRY N. | Chief of Patent Bureau, Thomson Electric Welding Co., 89 State St., Boston, Mass. | May 20. 1890 |
| TABER, ROBERT B. | Secretary and Electrical Engineer, New Bedford Gas Light Co., New Bedford, Mass. | Sept. 16, 1890 |
| TAYLOR, CHARLES | Metallurgist, U. S. Assay Office, 30 Wall St., New York. | Nov. 1, 1887 |
| TEMPLE, WILLIAM CHASE * | Electrical Engineer, 575 Madison Ave., New York. | May 3, 1887 |
| TESLA, NIKOLA | Electrical Engineer and Inventor, The Gerlach, 55 West 27th St., New York. | June 5, 1888 |
| THOMPSON, WILLIAM GEO. | MACNEILL, Resident Engineer, Sault Ste. Marie Canal, Sault Ste. Marie, Ontario. | July 12, 1887 |
| THOMSON, PROF. ELIHU | (*Past President*). Electrician, Thomson-Houston Electric Co., and Thomson Electric Welding Co., Lynn, Mass. | April 15, 1884 |
| TOBEY, WILLIAM BOARDMAN | Pittsfield Electric Light & Power Co., Pittsfield, Mass. | Sept. 16, 1890 |
| TOWNSEND, HENRY C. | (*Manager*). Attorney and Expert in Electric Cases, 5 Beekman St., New York. | July 10, 1888 |
| TREGONING, JOHN | Sup't, Thomson Electric Welding Co., 325 Boston St., Lynn, Mass. | April 2, 1889 |
| UEBELACKER, CHAS. F. | Brush Electric Co., and 1299 Euclid Ave., Cleveland Ohio. | Feb. 7, 1890 |
| UMLENHAUT, FRITZ, JR. | Field Engineering Co., 15 Cortlandt St., New York. | May 7, 1889 |
| UPTON, FRANCIS R. | (*Manager*). Treasurer and General Manager, Edison Lamp Co., Harrison, N. J. | May 17, 1887 |
| VAIL, THEO. N. | President, Metropolitan Telephone & Telegraph Co., 18 Cortlandt St., New York. | April 15, 1884 |
| VARLEY, RICHARD, JR. | Electrician, Okonite Insulated Wire Co., Passaic, N. J. | Mar. 18, 1890 |
| VAN BRUNT, WALTER | Manager, Duluth Telephone Co., Duluth, Minn. | Sept. 6, 1887 |
| VANCE, A. ST. CLAIR | 65 Fifth Avenue, New York. | April 2, 1889 |
| VAN TRUMP, C. REGINALD | Wilmington City Electric Co., Wilmington, Del. | Feb. 5, 1889 |
| VAN VALKENBURGH, F. S. | Central and South American Tel. Co., Tehuantepec, Mexico. | June 5, 1886 |

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| Name. | Address. | Date of Election. |
|---|---|---|
| VAN VLECK, FRANK | Chief Engineer, San Diego Cable Tramway Co., San Diego, Cal. | Nov. 16, 1886 |
| VIDUARRE, JOSE | Dealer in Electrical Supplies, Ponce, Porto Rico. | Sept. 6, 1887 |
| WACKER, GEORGE G. | Electric Organs, 3644 Third Ave., New York. | Sept. 6, 1887 |
| WALLACE, WILLIAM | Wire Manufacturer, Ansonia, Conn. | April 15, 1884 |
| WALTER, HENRY E. | Schenectady, N. Y. | April 2, 1889 |
| WARDELL, GEORGE P. | 19 Cedar St., Newark, N. J. | Nov. 12, 1889 |
| WARING, RICHARD S. | 205 Penn Building, Pittsburgh, Pa. | April 15. 1884 |
| WATERHOUSE, FRANK G. | Bolinas Bay, Bolinas, Cal. | Sept. 6, 1887 |
| WATERS, EDWARD G. | Electrical Engineer, Thomson-Houston Electric Co., 620 Atlantic Ave., Boston, Mass. | Mar. 18, 1890 |
| WATSON, ROBERT | The Elektron M'f'g. Co., 9 Washington St., Brooklyn, N. Y. | Oct. 21, 1890 |
| WATTS, H. FRANKLIN. | Electrical Engineer, Meriden Horse R. R. Co., Box 1001., Meriden, Ct. | May 20, 1890 |
| WEBB, HERBERT LAWS | Assistant Electrician, The Metropolitan Telephone and Telegraph Co., 18 Cortlandt, and 159 W. 94th St., N. Y. City. | Oct. 21, 1890 |
| WELLES, FRANCIS R, | Manufacturer, Bell Telephone Manufacturing Co., Antwerp, Belgium | Sept. 6, 1887 |
| WELLER, HARRY W. | Railroad Inspector, The Edison General Electric Co., Edison Building, Broad Street, and Jamaica, N. Y. | Oct. 21, 1890 |
| WHITE, H. C. | Manager, Phœnix Iron Works Co., 15 Cortlandt St., New York. | April 15, 1884 |
| WHITE, J. G. | J. G. White & Co., Electrical Engineers and Contractors, 50 Broadway New York City. | April 2, 1889 |
| WHITE, WILL F. | Electrical Engineer, Sec'y and Treas. Western Engineering Co., 448 Bee Building, Omaha, Neb. | Feb. 7, 1890 |
| WHITMORE, W. G. | Electrical Engineer, Edison General Electric Co., Edison Building, Box 3067, N. Y. C. | Mar. 18, 1890 |
| WHITNEY, HENRY M. | President, West End Street Railway Co., 81 Milk St., Boston, Mass. | July 12, 1887 |
| WIGHTMAN, MERLE J. | Vice-President and Electrician, The Wightman Elec. Mfg. Co., 4 Commonwealth Bldg., Scranton, Pa. | Mar. 5, 1889 |
| WILEY, WM. H. | Scientific Expert, 53 East 10th St., New York. | Feb. 7, 1888 |
| WILLIAMS, ARTHUR S. | Electrician, American Telephone and Telegraph Co., 18 Cortlandt St., New York City. | May 20, 1890 |
| WILLIAMS, CHARLES, JR. | Electrician, 100 Sudbury St., Boston, Mass. | April 15, 1884 |
| WILLIAMS, JAMES B. *M. D.* | 44 Broadway, Room 60, New York. | Sept. 7, 1888 |
| WINKLER, CHARLES F. | Electrician, Troy Electric Dynamo Co., 4 Park Ave., Troy, N. Y. | Sept. 3, 1889 |
| WINSLOW, I. E. | 458 Produce Exchange, New York. | Nov 12, 1889 |
| WINTRINGHAM, J. P. | Theorist, 36 Pine St., New York. | Ma 7, 1889 |

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| Name | Address | Date of Election. |
|---|---|---|
| WIRT, CHARLES. | Edison General Electric Co., Edison Building, P. O. Box 3067, N. Y. | Sept. 8, 1888 |
| WOLCOTT, TOWNSEND | Consulting Electrician, 849 Greene Ave., Brooklyn, N. Y. | Mar. 6, 1888 |
| WOLVERTON, B. C. | Electrician, N. Y. & Pa. Telephone & Telegraph Co., Elmira, N. Y. | Mar. 18, 1890 |
| WOOD, E. J. | Consulting Engineer and Contractor, 243 Broadway, New York. | July 12, 1887 |
| WOODRUFF, H. O. | Agent, Sprague Electric Railway & Motor Co., Des Moines, Iowa. | Oct. 2, 1888 |
| WOOLF, ALBERT E. | Electrician and Inventor, Woolf Electrical Co., 20 Nassau St. Room 50 and 864 Lexington Ave., New York City. | Sept. 16, 1890 |
| WORTHINGTON, GEORGE | Manager, *Electrical Review*, 13 Park Row, New York. | April 15, 1884 |
| WRIGHT, JOHN D. | Electrician's Assistant, United Electric Traction Co., 107 Garrison Ave., Jersey City, N. J. | Oct. 21, 1890 |
| YOUNG, ALDEN M. | Contractor for Organization and Complete Equipment of Electric Lighting Plants, 101 Bank St., Waterbury, Conn. | Sept. 6, 1887 |
| YOUNG, C. GRIFFITH | Superintendent and Electrician, Mount Morris Electric Co., Vandam and Greenwich Sts. New York. | Jan. 3, 1889 |
| ZALINSKI, EDMUND L. | Captain of Artillery, U. S. A., Care of War Dept., Washington, D. C. | May 17, 1887 |

Associate Members, - - - 335.

SUMMARY.

| | |
|---|---|
| Honorary Members, - - - - - - - - - | 3 |
| Members, - - - - - - - - - - - | 151 |
| Associate Members. - - - - - - - - | 334 |
| Total - - - - - | 488 |

Any errors in this list, or changes in address should be reported to the Secretary.

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## THE STANDARD WIRING TABLE.

DISCUSSION OF THE PRELIMINARY REPORT OF THE COMMITTEE BY THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, September 16th, 1890.

THE PRESIDENT (Prof. W. A. Anthony):—The first matter before us this evening is the report of the Standard Wiring Table Committee. The Secretary will read the action of the Council by which this was referred to the general meeting.

THE SECRETARY:—The Standard Wiring Table Committee was appointed by the Council some months ago, and has held several meetings, and at the meeting of the Council, June 17th, a preliminary report was submitted as appears from the following note in the minutes:

The preliminary report of the Standard Wiring Table Committee on Matthiessen's Standard, was presented by the Chairman of the Committee, Mr. Crocker. On motion of Mr. Wetzler, the report was received and ordered printed in the Transactions. On motion of Mr. Maver, it was resolved to submit this preliminary report to a general meeting of the Institute for action."

MR. GEO. M. PHELPS:—Will you please read the preliminary report?

Mr. Crocker read the preliminary report as follows:

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# PRELIMINARY REPORT OF THE "STANDARD WIRING TABLE COMMITTEE."

## In Regard to Matthiessen's Standard of Resistance of Copper.

The Council of this Institute at its regular monthly meeting held December 3, 1889, appointed a Committee "to formulate and submit for approval a standard wiring table for lighting and power purposes."

The Committee appointed consists of the following members of the Institute: Thomas P. Conant, Dr. Louis Duncan, Prof. Wm. E. Geyer, A. E. Kennelly, George B. Prescott, Jr., E. Wilbur Rice, Jr., Prof. E. P. Roberts, Prof. Harris J. Ryan, William Stanley, Jr., Dr. Schuyler S. Wheeler and Francis B. Crocker, Chairman.

This action was taken by the Council with the object of overcoming or reducing the great confusion which now exists in regard to the standards and constants of electric conductors.

At the first meeting of the Committee held January 10, 1890, it was decided to confine the work at first to the three subjects of Standards of Resistance; Temperature-Co efficient; and Safe Carrying Capacity of Copper, since these are of fundamental importance.

The subject of Matthiessen's Standard alone is so confused and involved, and the discrepancies are so great between the best authorities that the Committee has devoted its attention almost entirely to this subject up to the present time.

After a very thorough investigation of Matthiessen's work with a view to ascertaining what his Standard really was, by a sub-committee, consisting of Prof. Wm. E. Geyer, Mr. George B. Prescott, Jr., and the Chairman, the conclusion has been reached that Matthiessen's "mile standard" (one statute mile of pure copper wire 1-16 inch in diameter has resistance of 13.59 *B. A.* units at 15.5° *C.*) is not the true one although very com-

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monly used. We consider the correct Matthiessen's Standard and the one in which he himself had most confidence was the "metre-gramme" standard (resistance of pure hard drawn copper wire, one metre long weighing one gramme = .1469 *B. A.* Units at 0° *C.*) This has the disadvantage that it is expressed in terms of weight instead of diameter. It is, however, very much more difficult to get the exact mean diameter of a wire than to get its exact weight as Matthiessen himself states. Furthermore, by selecting the most reliable constants given by Matthiessen and corroborated by investigation and correspondence with the best authorities, we have by calculation converted this "metre-gramme" standard into a standard referred to dimensions and independent of weight, which is the form generally used.

The various constants selected, the method of calculation and the values deduced are given in a table at the end of this report.

As to the fact that wires may be found which test 102 per cent. of Matthiessen's standard or even higher, we are of the opinion that this is no real objection provided the value of the standard is definite and generally accepted. A standard which is not the highest attainable value may even be considered an advantage since the average commercial wires will approximate to it more closely.

Although we believe the standard we recommend will answer the purpose temporarily and probably permanently, nevertheless, we think that if a thoroughly correct and complete redetermination of the standard resistance of copper could be accomplished, it would be a benefit to electrical science and industry. Favorable offers in this direction have already been received by this Committee from Johns Hopkins University, Cornell University and Columbia College, and it is very likely that this redetermination may be undertaken.

This Committee purposes next to take up the subject of the safe carrying capacity of wires.

Matthiessen's standard recommended by this Committee is:

A hard drawn copper wire 1 metre long weighing 1 gramme ("metre-gramme") having resistance of .1469 *B. A.* units at temperature 0° Centigrade.*

From this standard we calculate by taking the value 8.89 for the specific gravity of copper, that a hard-drawn wire 1 metre long and 1 millimetre in diameter ("metre-millimetre") has a

* *Philosophical Magazine*, May, 1865.

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resistance of .02104 *B. A.* units at 0° *C.* This value is also given by Matthiessen.†

Matthiessen's figures ‡ for relative conducting power are:

| | |
|---|---|
| Silver | 100 |
| Hard or unannealed copper | 99.95 |
| Soft or annealed copper | 102.21 |

From these the resistance of hard copper is found to be 1.0226 times that of soft copper, therefore the resistance of a soft copper wire 1 metre long and 1 millimetre diameter is .02057 *B. A.* units at 0° *C.*

From this the resistance of 1 cubic centimetre of soft copper is found to be .000001616 *B. A.* units at 0° *C.*

And the resistance of soft copper wire 1 foot long and .001 inch in diameter (mil-foot) is 9.720 *B. A.* units at 0° *C.*

Taking one *B. A.* unit as .9889 legal ohm any of the above values may be converted into legal ohms. To find the conductivity of copper at temperatures other than 0° *C.* Matthiessen's formula may be used $C_t\ C_0\ (1 - .00387\ t + .000009009\ t^2.)$

TABLE OF VALUES BASED UPON MATTHIESSEN'S CORRECT STANDARD.

| | B. A. Units. 0° *C.* | Legal Ohms. 0° *C.* |
|---|---|---|
| Matthiessen's Standard metre-gramme, hard | .1469 | .1453 |
| Metre-gramme, soft | .1436 | .1420 |
| Metre-millimetre, hard | .02104 | .02080 |
| Metre-millimetre, soft | .02057 | .02034 |
| Cubic centimetre, hard | .000001652 | .000001634 |
| Cubic centimetre, soft | .0000001616 | .000001598 |
| Mil-foot, hard | 9.940 | 9.829 |
| Mil-foot, soft | 9.720 | 9.612 |

Specific resistance of hard copper (1 cub. cent.) = 1634 (C. G. S. units.)
Specific resistance of soft copper (1 cub. cent.) = 1598 (C. G. S. units.)
Matthiessen's Standard specific gravity of hard copper, 8.89.
Resistance of hard copper is 1.0226 times that of soft copper.
Resistance of soft copper is .9779 times that of hard copper.
Legal ohm is equal to 1.0112 B. A. units.
B. A. unit is equal to .9889 Legal ohms.

F. B. CROCKER,
*Chairman.*

(NOTE.—This report has since been revised in accordance with the instructions of the meeting of Sept. 16, 1890. R. W. POPE, Secretary.)

† *Philosophical Magazine*, May, 1865.
‡ " *Transactions*, 1864.

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Mr. Crocker continued as follows:

"Of course the derived values follow as soon as the fundamental standard is decided on, and the question therefore is, not what the derivations are, but whether the fundamental standard is correct; in other words, whether Matthiessen's 'mile standard' or Matthiessen's 'metre-gramme' standard is the more reliable. Now the sub-committee has investigated this particular point with a great deal of care and arrived at a very definite conclusion: that the metre-gramme standard was unquestionably the more accurate and the more reliable of the two, and that Matthiessen himself so considered it. Fortunately, after having decided this, we received a letter from Mr. Latimer Clark, who is one of the best authorities on this matter, and who was a contemporary of Dr. Matthiessen: in fact he suggested to Dr. Matthiessen that he undertake these experiments, so he is especially competent to express an opinion on this subject, and he agreed with our conclusions in every respect. We had already arrived at these conclusions, so his letter was simply corroborative. Mr. Latimer Clark's letters to the Committee covered the subject very thoroughly and clearly, and I wish here to express our thanks to him for his kindness. There is, however, considerable confidence in the mile standard, and I think simply for the reason that it has been used, and the fact that a mile, and the sixteenth of an inch are more familiar values for the ordinary American and English engineer than a metre and a gramme, but the metre-gramme is just as capable of being transformed into practicable and common units as the mile, and sixteenth of an inch. The necessity for deciding on some standard is more urgent than would be ordinarily supposed. This morning for instance, in my ordinary professional work, I referred to two wiring tables issued by presumably competent persons, and both intended to be correct and both being such as an engineer would use in his practice. One of these tables gave the resistance of No. 25 B. & S. gauge copper wire as 33.4 ohms per pound at 75 deg. Fahrenheit. The other gave it as 34.7 ohms per pound at the same temperature. Now there is a difference of 1.3 ohms in 33 ohms, which is about 4 per cent. In some cases it does not make very much difference whether it is 4 per cent. one way or the other, but 4 per cent. is a very considerable discrepancy, and in a great many cases it would make a very serious difference. For instance, I was figuring on sixteen pounds of wire and it made a difference of almost 21 ohms. That is not only measurable, but it is a serious matter in some cases. I think that when two wiring tables that electrical engineers ordinarily use, differ by 4 per cent., it is time to do something. I just happened to pick up these tables this morning. I did not do so with reference to this subject. I dare say if I looked for discrepancies I could find much greater ones. The adoption of this standard does not mean that every wire used for commercial purposes shall be 100 per cent. of Matthiessen's stan-

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dard. There is no reason why an electrical engineer in his specifications should not require 101 per cent., if he considers it necessary, and I can think of cases where it might be necessary. On the other hand, it might be sufficient if the conductivity was 97 or 98 per cent. of the standard. It is simply necessary that we should have some definite value.

The question whether any standard at all is necessary is a more important one; as it is not absolutely necessary to have a standard. We could simply say that one mil-foot or one cubic centimetre of the copper used for a certain purpose should have such and such resistance—in other words a certain specific resistance. But practical men have become accustomed to using Matthiessen's standard, and they seem to want a standard, and they will use one whether we want them to or not; such being the case I think it better to decide what Matthessen's standard is. It certainly is commonly used. You see the expression in every book and almost every paper and specification, and as it now has no definite value—even though it is not used in the future, just simply to have it settled once and for all, I think it would be well to settle upon a definite standard. We feel sure that the Institute will make no mistake in adopting this as Matthiessen's standard, and unless there is some particular objection to it which has not been brought out by our investigations, we hope the Institute will do so.

Mr. George B. Prescott, Jr.:—In making this report, the Committee has not thought it necessary to go into details very much, and it may be interesting to members of the Institute to know how this discrepancy in what is called Matthiessen's standard has arisen. In the first place, it is perhaps worth while to inquire why this standard was adopted in preference to any other. The reason was, because Dr. Matthiessen made a series of careful experiments to determine the resistance of metals and the variation of their resistance with changes in temperature, which extended over a great number of years and formed the basis of the work of the British Association which decided on the practical standards. It seems that years before this British Association Committee undertook this labor, various standards of resistance had been proposed by German, French and English electricians, and they were of all kinds, and among them was one proposed by Dr. Matthiessen, which was this "standard mile." There were no ohms in those days, and he made up a standard mile of this copper and that was used as a unit in England for a long time. Later on, when the Committee of the British Association had determined the value of the ohm in absolute units and had prepared practical standards, part of this Committee tested the different standards that had been made in different parts of the world, including this standard of Matthiessen, and when they measured it they found that it was equal to 13.59 British Association ohms. Matthiessen never gave it that value; it was sim-

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ply an arbitrary standard that he selected, because it was a convenient unit. Probably it was the size of wire commonly used in those days. So that really it never was a standard except in that sense. After Matthiessen's work was completed and published, Dr. Fleeming Jenkin, who was the Secretary of the Association, tabulated the results. Matthiessen's measurements were made with respect to weight and length, and also diameter and length. But his measurements of diameter were always very unsatisfactory, and finally the only measurements that he really relied on were those of length and weight. But he made a very great mistake, which he himself acknowledges in his reports, which was, that he neglected to take the specific gravity of the actual samples that he experimented on, and the result, of course, is easily understood. Every sample of copper varies somewhat in its physical properties, and if you were to take one hundred samples of wire and measure their resistance at a given weight and length, and then attempt to calculate the resistance from the cubical dimensions, you would find a difference, simply because there is a difference in the drawing of wires which changes their molecular constitution. Dr. Matthiessen neglected to take the specific gravity of any sample of wire that he tested, and the result is, that we do not know to-day what Matthiessen's standard is except in terms of weight and length.

A further complication arose in this way, that Dr. Fleeming Jenkin, who as I say, tabulated the results which Dr. Matthiessen obtained; made all sorts of derivations, giving the resistances in foot-grains and foot-mils and metre-grammes and metre-millimetres—all by calculation. Of course in converting from length and weight into length and diameter he had to use specific gravity. He selected certain specific gravities. In his original table there are errors. Those errors have been copied. Other people have calculated tables from the standard mil unit, and of course they give different results, so when Matthiessen's standard is referred to to-day, there is a great deal of uncertainty as to which standard is meant. As a matter of fact, the statute mile standard is probably nearer the true resistance than the metre-gramme, for the reason that it gives a higher conductivity, and there have been any number of cases of wire being tested that had greater than one hundred per cent. conductivity, and it was for this reason that seven or eight years ago I calculated a wire table, and selected this unit of Matthiessen's simply because it was the lowest, and agreed with some results that I had actually obtained.

Mr. George G. Grower:—I think there is a mistake made when hard copper wire is assumed as the standard and the resistance of soft copper reckoned from it. This takes for granted that there is a fixed ratio in resistance between hard and soft copper. But this ratio depends entirely upon the hardness of the hard copper compared with the soft. For instance, if you

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take large copper wire and have it as hard as you can get it, the conductivity would be almost as good as soft copper, while in a small wire it would not be nearly so good. I have had as much as eight per cent. difference between hard and soft copper made out of exactly the same stock on small wires. If we should make the wire very small, I dare say it would make still more difference.

I agree with the Committee that the metre-gramme standard is the more reliable, because whenever I have tried to make tests with diameter I could not get any sort of agreement among them; but where I take soft copper standard, no matter what the size of the copper is or anything else, so long as it is soft copper, and from the same stock, I get almost the same result. But if you take hard copper for the tests, the results will differ several per cent., according to the size of the copper. I think for that reason the standard should be soft copper of a given length and weight.

MR. CROCKER:—It is perfectly correct as an abstract statement that soft copper is more constant in its resistance than hard copper. Hard copper can be made of almost any resistance up to several per cent. above soft copper. But soft copper is not Matthiessen's standard. It is precisely like the case of the foot. The English foot originally, I have heard, was the length of the King's foot. Well, now, at the present day, I think it is a little in excess of the average length of the human foot. But it does not make a particle of difference, provided it has a definite value, and it has, and providing a correct copy of the standard is kept in a safe place—it does not make any difference whether it is an inch longer or an inch shorter than the human foot. It has a definite value, and no one, I think, at the present time, would recommend changing the English foot, as a unit of measurement, to agree more closely with the length of the anatomical English foot. It is precisely the same with Matthiessen's standard. Unfortunately or fortunately, as you may look upon it, Matthiessen has promulgated a standard and it has been largely, in fact almost universally accepted. Now all that is necessary is to adopt a definite value for this standard. It does not make much difference what it is, provided it is definite and generally accepted. Of course in selecting a definite value we want to select the best one, the most reliable one, the one that he has himself considered most reliable, and the one that other authorities deem the best. So it seems to me that the mere fact that one standard or another approximates more closely to what the highest possible value is, or the fact that one or the other happens to be easier to determine in practice, makes no great difference, provided we get a certain definite standard or resistance for various lengths, weights, diameters and kinds of copper. I think that all that is necessary is to free this subject from its great confusion by simply adopting a definite standard, and if that stand-

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ard happens to be more correct than some other, so much the better; but even if it is not, it is very much better than confusion.

DR. LOUIS BELL:—As regards this question of standards, I suppose that standards must be established, but it is not a pleasant task for the man who has to do it. Of course everybody now understands perfectly well that Matthiessen's standard does not represent the actual resistance of chemically pure copper, either soft or hard. It represents those particular specimens of copper which he had in hand, and fortunately happens to represent something that is pretty nearly good commercial copper in every day use. Now what is to be gained in going to work and obtaining the purest copper that the chemist's art can give us and then working out all our wiring tables on that basis, if after all this labor and trouble, we have the result that we are compelled every time we calculate commercial copper to multiply the values of those wire tables by .984362 or some such unpleasant decimal, which would make everybody very tired who had the misfortune to have anything to do with it. If we had a perfectly sharp and definite standard of the purest copper obtainable, we would not be able to use it, but would have to transform it to some other value which meets commercial conditions. I very cordially agree with the recommendation of the Committee to take as a standard something that is generally accepted and does represent what we can reach in commercial practice. With a table made up on that basis a man can buy his wire with a certain feeling of confidence that its resistance is going to be pretty nearly what is laid down in the table, and that he will not have to multiply by any complex fraction to find what the real resistance of the sample he has bought is likely to be. The Matthiessen standard recommended by the Committee, simply does represent the commercial copper of the day; not very good commercial copper either; and for this reason that it does represent what we can readily obtain and what we can count on buying, I believe this standard even though it is not the strictly absolute standard of copper resistance, is an excellent practical working value to use until we have some complete determination of the conductivities of metals. There is, by the way, great need of that, and I hope it will be done. I hope the offer received by the Committee will be taken up and that the subject will be worked over, because in the resistance of metals other than copper, there is a still greater discrepancy than we find in copper. But pending that, and perhaps for future time quite independent of the results that may be reached in such a research, I believe that the practical standard proposed by the committee is an exceedingly good one.

MR. CROCKER:—In regard to what Dr. Bell said about the Matthiessen standard, fortunately agreeing with ordinary commercial copper, I think that is a strong recommendation in its favor. I see no practical reason, certainly, for spending months in ob-

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taining copper purer than has ever been obtained before, and purer than any ordinary user of copper can ever expect to obtain, and determine its resistance, and then call that the standard. There may be some scientific reason for it, but there is certainly no practical reason. Now a standard like Matthiessen's is simply a commercial standard. It is used incidentally in scientific work as a definite value, but that is not its primary object. Its primary object is an ordinary, definite, practical standard of resistance of copper, and the nearer that standard approximates to commercial averages, so much the better; and if we succeed in getting a wire which is 103 per cent. of Matthiessen's standard, and I think it would be possible to do that, I do not see that it would vitiate the standard a particle. I think Dr. Bell rather overrates the average conductivity of commercial wire. I think if one succeeds in getting wire of 100 per cent. Matthiessen's standard every time, he would be doing very well, and I think that most specifications do not call for more than 96 to 98 per cent. Matthiessen's standard, which shows that the standard is such that the very best commercial wire just about reaches it and ordinary wire just falls below. The highest point at which reasonably good copper wire would go under commercial conditions, I think is exactly where the standard ought to be. I suppose the tendency is for the conductivity of copper to go up all the time with improved methods of manufacture, but I doubt whether it ever gets much above Matthiessen's standard, and I think it may get so that the best copper is about equal to Matthiessen's standard. So, as Dr. Bell says, it fortunately agrees with commercial values.

Mr. William Wallace:—There is one thing to be considered, —that there are so many degrees of hardness and softness. You can get copper extremely hard or soft and get all the range between, and that plays a very important part in this question. I have heard very little said about that. It is a thing, I think, that ought to be looked into.

Mr. William B. Halsey:—How would it do in practice if silver were used as the metal which the standard should be made of? Is there as much variation in the hardness and softness of silver as there is in copper? Or would aluminum be a better metal yet?

Mr. Prescott:—I can answer that. Dr. Matthiessen used silver as the standard, and a great many of the discrepancies that occur in his results are due to the fact that at different times he used different standard wire, so that when he came to compare a copper wire that he had tested with one silver standard and then later by another silver standard, he would get discrepancies, and all through his report you will find difficulties of that sort which he himself pointed out. There is one other point that I would like to mention—that is the question of the temperature-coefficient for copper. Mr. Crocker, I think, neglected to read the value

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given by Matthiessen, which we have picked out very carefully; and I want to call your attention to another curious error that has crept into the text-books in regard to this temperature-coefficient. Matthiessen gave the value in terms of conductivity at zero temperature multiplied by a certain constant. This constant is composed of three terms, and there s a minus sign before the second one. Now conductivity is not so commonly used as resistance, therefore to make this formula generally useful the text-books have converted it into terms of resistance and in doing this they have invariably, so far as I have found merely changed the signs. What they should have done was to take the reciprocal of this value and the reciprocal changes second term of this constant, and that correction has never appeared anywhere that I am aware of excepting in an article which I published in the *Electrical Engineer* some little time ago calling attention to it. This is rather an interesting thing. Matthiessen's formula for the temperature coefficient is this:

$$Ct—C_0 (1—.00387t + .000009009t^2$$

This same formula is also commonly used for resistance, merely with the first sign changed. But if the correct reciprocal value is taken, the value of the second term will be considerably altered.

Dr. William B. Geyer:—I suppose that this report, so far as the verbal part of it is concerned, is more or less provisional. As a member of the sub-committee on Matthiessen's standard, I am perfectly familiar with all its contents. But a few days ago, I wrote a letter to the Chairman, suggesting certain changes in the sense expressed by Mr. Grower, namely: that we ought not to speak of Matthiessen's standard as being the resistance of a certain sample of hard copper, but we ought to speak of it as being the resistance of a certain sample of soft copper, which latter Dr. Matthiessen also gives, and the reason is. as Mr. Grower just said, that hitherto all coppers, even hard copper, have been compared with pure annealed copper as being the highest conductivity generally known, and if that report is provisional, as far as the wording goes; I would again suggest that it be modified in that direction.

Mr. Crocker:—I think that objection can be overcome by simply stating that Matthiessen's standard for hard copper is such a value, and for soft copper is such another value, giving them equal prominence, they being unquestionably Matthiessen's standards for hard and soft copper respectively. In other words there is no reason for pushing one of them ahead of the other. They are derived from each other directly, and this objection seems to be really more verbal than material.

Dr Geyer:—I think there is an objection to speaking of both hard and soft, especially as hard coppers are of all degrees of hardness. It is true, too, that soft coppers are of all degrees of softness; but when we speak of annealed copper we think of it

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as being annealed as well as it can be, and practically all coppers, hard and soft, should be compared with something that is supposed to be perfect.

MR. GROWER:—In regard to the relative degree of hardness and softness of copper, I might say that out of numerous tests I have made with copper, half an inch or over in diameter down to one or two thousandths only, I have not found as much as a half per cent. difference in soft copper. Although I never tested any very small hard copper, I got as much as eight per cent. difference, nearly nine per cent. difference, between different standards of hard copper or different sizes made of the same stock. Precisely on that ground alone I think that is is not right that any standard of hard copper should be accepted, because it leads to the inference of a certain ratio between the conductivity of hard and soft copper. I think with very small hard copper, we could get fifteen or twenty per cent. difference. The wire that I tried was not small. It was about No. 22; I am not sure precisely what it was.

THE PRESIDENT:—It would seem to me that it would be better to recommend only one standard, from the fact that what we are after is to establish some sort of a standard on which wiring tables can be computed. It is not the idea, as I have understood it, that we are trying to establish a standard material from which the resistance of copper could be determined. That is, if a person has lost all his standards of resistance he could not go and pick out a piece of copper wire and measure off a piece a metre long and weighing one gramme and say this shall have such and such resistance, and take that as a standard and go to work and determine the relative resistances of other pieces. That would be out of the question He could not obtain a sample of copper exactly like what Matthiessen used. But what we do want to do, is to fix upon some standard length and weight, or length and diameter as having a certain resistance. That is, we shall say that a certain piece of copper of any certain degree of hardness or purity, of a certain length, at a certain weight, has a certain resistance, and then go to work and compute our wiring tables, putting in all that we ordinarily put into wiring tables. Now we have something that is perfectly definite. This wiring table says that a copper wire a mile long and one-tenth of an inch in diameter, we will say, measures 5 ohms. Very well. If we find that we have a piece of copper wire that is a mile long, and one-tenth of an inch in diameter, that measures 4.9, why the resistance is 98-100ths. of the standard. We do not care what the standard is. So that it seems to me that what we want to adopt here is some one standard, not two. We do not want two wiring tables. We have half a dozen wiring tables now; and it is just what we are after to get rid of different values, and if this Institute adopted this standard to-night with these two values in it, it seems to me that we should find somebody by-and-by calculating a wiring table on one of

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them and publishing it and sending it out all over, and somebody else would calculate a wiring table on the other standard and send it out also, and then we should have two wiring tables.

DR. GEYER:—Another reason suggests itself to me as to limiting the standard to one value, and more particularly the value of soft copper. There are two valuable qualities in copper sought after—conductivity and tensile strength. If you want to get the tensile strength you lose conductivity. If you want to get conductivity you lose tensile strength. Now, if the two things could be combined in one, that would be a very valuable property. Suppose one manufacturer aims at tensile strength and he is asked what is your conductivity. Well then, he will probably calculate by hard copper and say, "Oh, my conductivity is so high—very high indeed." Then this sample will be sent to somebody for testing. He will examine it and perhaps use a hard copper standard, or perhaps use a soft copper standard, or perhaps report on both, and in that way confusion is at once introduced. Let a man make up his mind what he wants—whether he wants conductivity and sacrifices tensile strength to that, or wants tensile strength and sacrifices conductivity to that.

MR. CROCKER:—I agree with the President and Dr. Geyer in the inadvisability of having two standards. I forgot for the moment that two would cause confusion. I think that one standard had better be adopted. The avoidance of confusion is paramount.

THE PRESIDENT:—I think that the soft copper is the better standard for the reason that soft copper is much more definite than hard copper. The hard copper, as I understand it, varies so greatly in hardness that if we have a hard copper standard it is not likely that any other hard copper would agree with that standard. We might have a hard copper that differed by four per cent. from soft copper, or a hard copper that differed by one per cent. from soft copper; so that the hard copper standard would not have any definite relation to the hard copper standards in commercial use; while with annealed coppers of the same purity we may expect that they will pretty well agree with each other.

MR. FRANKLIN L. POPE:—I move that the provisional report of the Committee be adopted with the recommendation that the standard be expressed in terms of soft copper—Matthiessen's value.

The motion was seconded and carried.

THE PRESIDENT:—Now it seems, as this is only a preliminary report, the matter is still in the hands of the Committee for further action by-and-by.

MR CROCKER:—I should rather have the matter definitely decided to-night. I doubt if it will be again taken up by the Institute for some time to come, and there seems to be no great conflict of opinion in regard to it.

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MR. GEORGE M. PHELPS:—I understand that we have now definitely adopted the report of the Committee as amended by the suggestions that have been made and that the Matthiessen's metre-gramme standard is adopted. That seems to me to be disposed of. But I understand the President implied in what he said that the Committee perhaps had better be continued to finish the rest of its work, and therefore I move that the Committee be continued to report at some later convenient time.

MR. PRESCOTT:—On what?

MR. PHELPS:—You were going to get up some wiring tables.

MR. CROCKER:—There is lots of work ahead for the Committee and the Committee proposes to undertake it, but it would relieve our minds very much and encourage us to go farther and do better if we felt that part of our work had been accepted.

THE PRESIDENT:—The Chairman understood that this motion adopted the Matthiessen standard for soft copper as reported by this Committee as the expression of this Institute; that that part had been adopted and settled, and the suggestion was that the Committee should now proceed to the further work, as this is only a preliminary report.

MR. PRESCOTT:—As I understand it, the Committee will make this revision that has been suggested in this report and that then it will be published in the Transactions without further submission to the Institute.

THE PRESIDENT:—That was the understanding of the Chair.

MR. PHELPS:—I think that is quite important, Mr. Chairman, although it would not be exactly in conformity with what has taken place here; but it would be important that this report, when it is published, should be quite clear. Therefore, as Mr. Prescott suggests, that report before printing should be revised in the sense in which it has been accepted by the meeting. Then it would not be open to any one to make any difficulties on the record.

A MEMBER:—I would like to ask whether the gentleman referred to some action of Johns Hopkins and Columbia Colleges and some other institutions in reference to the subject, and if the Committee have any recommendations to make.

MR. CROCKER:—The Committee at first thought that a standard should be detemined with the best modern instruments and with the best attainable copper but what we require after all is simply a definite standard, and although it would satisfy our curiosity to have the highest attainable conductivity of copper detemined, I doubt if it would benefit science or electrical industry very much to have it done. At one time we had decided to go ahead in that direction and we were very much encouraged by the offers of assistance which were given to us, but I think now it would simply be a matter of deciding the highest attainable conductivity in terms of Matthiessen's standard, which of course would be an interesting thing to find out, and it might possibly

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be used as a standard of some sort or be of benefit to electrical science in other ways.

MR. ROBERT S. DOBBIE:—If this metre-gramme standard is decided on, it is equally important that the specific gravity should be determined. Do I understand from the Chairman of the Committee that we had definitely decided on a certain value given to Dr. Matthiessen?

MR CROCKER:—Yes, it follows as a matter of course that a certain value of specific gravity is Matthiessen's value. But this is all arbitrary. Unfortunately Matthiessen did not determine the specific gravity of his particular sample. But the only specific gravity which will make his two values agree is 8.89, which therefore is Matthiessen's value for the specific gravity of copper.

MR. ROBERT S. DOBBIE:—That is the specific gravity of soft copper?

MR. CROCKER:—No, hard copper. We simply take the value given by Matthiessen for soft copper, and adopt that as our standard. That involves this specific gravity in deriving it, but after the standard is once arrived at and adopted, the specific gravity used in getting it ceases to be important.

MR. DOBBIE:—That soft standard has been adopted by the vote of the Institute.

MR. CROCKER:—Yes, and that necessarily assumes specific gravity in deducing it, but now it applies to all copper of all specific gravities.

DR GEYER:—The determination of the highest conductivity obtainable in copper is, I think, simply an interesting scientific question not having much practical importance. I think the determination of the specific gravity of commercial copper is of some practical importance, and I have proposed to myself, at an early opportunity, to get a large number of samples of commercial copper in order to see what really is the specific gravity of commercial copper. As Mr. Crocker has stated, the specific gravity, 8.89, is simply one deduced from Matthiessen's figures; it is to that extent an assumption. We are compelled to take that, in order to harmonize the conductivity in terms of weight and length, as stated by him, with the conductivity in terms of length and diameter as also stated by him. Possibly he made the determination of a sample and found that specific gravity, although, as far as I recollect, it is not definitely stated. Now, if it should be found that the specific gravity of commercial copper is 8.89, then it will be perfectly correct to go from his metre-gramme system where resistances are stated in terms of weight and length, to a system which is more commercial, where resistances are stated in terms of length and diameter.

A MEMBER:—I would like to ask—and this is a question which has attracted a good deal of attention across the water, especially in England and Germany—how this standard would compare

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with the present knowledge of the matter in France, England and Germany.

DR. GEYER:—As far as the standard goes, I think in Germany they very largely refer conductors to mercury, which has some scientific advantages, though practically it is not a good way to do it, and in this country I do not think it will be ever introduced where people have got into the habit of referring to the Matthiessen standard.

DR. BELL:—It does not seem necessary to offer any more embarrassing suggestions in the way of the Committee; but there is one point mentioned by Mr. Crocker to which I would like to take exception, and that is the legal ohm part; because it happens that the British Association at its Leeds meeting has recommended a new value for the legal ohm which ought to come under careful consideration, recommending the standard mercury column 106.3 centimetres long instead of 106 as assumed by the Paris Conference in 1884, and that change will probably come up in active form very shortly. So that I simply throw that out as another little suggestion to the Committee in their already complicated task.

MR. CROCKER;—I think that the Committee would have to have a daily cablegram from London to keep themselves up to date on the question of the value of the legal ohm, and the Committee has no appropriation for cablegrams. Possibly it would be better to give Matthiessen's standard in terms of B. A. units, and then from time to time, as the whims of foreign electricians went one way or the other, we could modify our figures to suit the legal ohm at that particular time. In fact, Matthiessen's standard, bad as it is, is about as definite as the ohm.

MR. PRESCOTT:—Although we have adopted Matthiessen's value for soft copper definitely, and I think there are good practical reasons for doing it, as a member of the committee I would like to show the historical and logical reasons for adopting the hard standard which we did. The wires that Matthiessen tested were all hard samples, the ones that he made the ultimate measurements of. He determined the relative resistance of soft copper by comparing pieces of soft copper with the resistance of hard samples which he had measured, and he did not make, so far as I have been able to ascertain, any distinct measurements of soft copper, but derived it purely by relative measurements.

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## THE UNIT OF SELF-INDUCTION.

THE SECRETARY:—The next subject to be discussed and acted on is the adoption of an American name or names for one or more practical electrical units. This matter was also referred to this meeting by the Council, June 17th. The resolutions have been printed in all the papers, and I have them here if the members wish them read.

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THE PRESIDENT:—Do you desire the reading of the resolutions?

The reading of the resolutions was called for and the Secretary read them as follows:

*Whereas.*—It has been the custom in the nomenclature of electrical units to perpetuate the names of men who have contributed most to electrical science, and

*Whereas.*—In the names thus far adopted the eminent services of Americans have not been recognized, therefore

*Resolved.*—That in the opinion of the American Institute of Electrical Engineers, a just distribution of the honors thus bestowed necessitates a recognition of the splendid contributions to electrical science of one or both of America's great electricians—Benjamin Franklin and Joseph Henry; and,

*Resolved.*—That this Institute will gladly co-operate with other bodies in this country and abroad to secure the general adoption of these names for electrical units; and,

*Resolved.*—That the name of Henry should be given to the practical unit of self-induction, since he was the discoverer and greatest investigator of this phenomenon, and because this unit at present is called a quadrant, which is merely a numerical value and not a suitable name.

*Resolved.*—That this Institute recommend to electrical societies and electrical engineers the general use of the name Henry for the unit of induction as being the quickest and surest way to secure its final adoption.

DR. SCHUYLER S. WHEELER: Mr. President, is not a resolution now before the Institute?

THE PRESIDENT:—The resolution just read is now before us, having been referred to a general meeting by the vote of the Council.

THE SECRETARY:—I do not understand that it is to be finally acted upon at this meeting.

DR. WHEELER:—Is there any difficulty in acting upon it finally?

MR. CROCKER:—None that I am aware of, and I urge that it be acted upon unless there is some objection. I introduced this resolution at the Council meeting and hoped for some action there, forgetting that it was hardly within the province of the Council to take final action on a matter of this sort, and it was deemed best to refer it to a general meeting of the Institute, but I think that is sufficient and that a general meeting of the society is perfectly competent to act on this matter. As to the advisability and propriety of doing it, I see no objection. In fact the idea has been received very favorably by electricians abroad, and the only point that there can be any question about is whether Henry is clearly entitled to the discovery of self-induction. Henry's orginal paper, which antedates by two years anything that Faraday did in that direction (the only other man who could be entitled to be called the discoverer of this phenomenon) was printed in the year 1832 in Silliman's Journal and distinctly describes the phenomenon and states that it is due to the action of the current on itself, that is to say—self-induction.

As to the word "henry" for a unit, I think it is rather better than the everage. Some of the names of electrical units are very good. They are almost all of them unique and different from

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anything else. Ohm, Volt, Ampere, Coulomb and Henry never would be mistaken for anything else, because they are proper names and the context would always clearly distinguish them. Henry seems to be eminently suited to be the name of an electrical unit. It is shorter than ampere and coulomb. It is as short as joule and farad and is almost as short as the very short words ohm and volt. It only differs from volt which is an extremely short word, by one letter. So I see no reason for abbreviating it, although it has been suggested by Dr. Fleming to abbreviate it to "hen," which I think is open to several serious objection. The first is that the names loses its identity. Faraday may be abbreviated to farad and everbody would know what it came from, whereas if you abbreviated it to "far" nobody would know what it meant. And the same way with henry. I think if it is abbreviated to "hen" it loses its identity entirely.

Now I think it better not to state exactly what the value of a "henry" is. Whatever the unit of self-induction is decided to be, let that be called the "henry." If we fix a certain value to the "henry," and the unit of self-induction is made something else, that would cause trouble. So I think we had better leave a blank for the value of the "henry." The present unit, in my opinion, is rather high and it might be cut down.

The number of units that have been allotted to different countries is rather interesting. We have farad, watt, and joule for England. We have ampere and coulomb for France We have ohm for Germany and volt for Italy. Those are all I recollect now. I think that England and France had better wait until the other countries catch up to them. Dr. Fleming tries to put in another English name with this American name. In that way the English would get another unit every time any other country got one, and thus keep a controlling interest in units as it were. But I do not think that is at all necessary. They already have three, and although their contributions have been large, they have not been infinite as compared with American contributions, as the ratio of 3 to 0 would imply, and I think we ought to have one or two, to say the least, before England gets another. The fact that all other countries have one or more, and we have nothing is really something to take action upon. It is almost an insult to American electrical science that there is not any unit named after an American, and in the future, people will think there must have been some reason for it, that something must have been the matter with our electrical engineers at this time or they would have had a unit named after them or seen that there was a unit named after some American electrician. It is not only a slight to the men for whom the unit should be named, but it is a reproach to the men who do not make it their business to see that some unit is named after some American, and therefore I hope that this, or some equivalent resolution will be adopted.

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DR. WHEELER:—I move the adoption of the resolution that the Secretary has read.

(The motion was seconded.)

DR. BELL:—I am heartily in accord with this resolution, but I must say that we may make our blanket so large that we shall find it covering some very undesirable things. In other words I feel very sure, and I think all my associates will agree with me in that, that if we pass this resolution and put the word "henry" into use to represent the unit of self-induction, it will be used in every case as the synonym of the present unit. In fact it has been so used since its first suggestion, and I believe if we ever make this like o her names derived from the names of men, the name of a practical unit, we should endeavor to have it represent a unit which can be conveniently used in practice. I do not believe that any electrician ever had occasion to encounter the unit of capacity without indulging in animadversion on the men who got it out. We not only use microfarad, but the customary standard you find around laboratories is one-third of that. The earth's quadrant is unconscionably large. It makes even apparatus of high self-induction have a fractional value in terms of that unit. For example, we should have induction coils, etc., having fractional values of self-induction, say, .256 of a "henry." While we are selecting a practical unit, I think we should take a value which will be convenient in actual every day computation, so that when we are talking about it in a few years, we shall not be driven to using small fractions every time we want to express ourselves. I believe that rather than blanket the entire universe with a name, and letting it settle itself, we should confine it and push that definition into use as well as we can. If we do not confine it, it certainly will mean the present unit, which is not a practical unit at all. I believe that in pushing this resolution, we should make the "henry" a practical unit of say one hundreth the value of the present inconvenient absolute standard.

MR. PRESCOTT:—I would suggest that Dr. Bell present that in the form of an amendment.

DR. BELL:—Mr. President, I will make that as an amendment—that in passing this resolution, it is the sense of the Institute that this name should be applied to a practical unit, in value one one-hundredth of the earth's quadrant.

The motion was seconded.

MR. CROCKER:—I will suggest that this be added as another clause to this resolution so that it does not involve the rest of it. What is said in the resolution is that the name "henry" should be given to the practical unit of self-induction. That, so far as it goes, is all right.

DR. BELL:—I suggest one one-hundredth because I think it would fall more conveniently into practice. For example, I believe that the self-induction of the telephone instrument is somewhere about one one-hundredth of the quadrant, and the self-induction

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for ordinary induction coils, for example, would be half a quadrant, and values of that sort. Now, if we took one-tenth of the practical unit which would be a million metres, we should still have fractional values for a large number of common instruments and common coils. It is for that reason I suggested taking a smaller figure. A thousandth might be practical, although it would make numbers somewhat larger. The one one-hundredth seems to be about the magnitude to make the self-induction which we ordinarily meet in practice, small whole numbers.

I am thoroughly in accord with Mr. Crocker's suggestion that this simply be added as a clause in the original resolution. I think it would serve the purpose there as well as anywhere else, because we simply fix the name "henry" and then recommend the practical unit, so that the two things would naturally go together.

DR. WHEELER:—It seems to me that the work of selecting that fraction of the unit, which would be most convenient for use, is committee work, and it would be well to accomplish what Dr. Bell wants to accomplish by passing the first part of the resolution, and then making his resolution read, "And the selection of this unit shall be left to a Committee appointed by the Chair to report at the next meeting."

DR. GEYER:—I think we ought to do that. The adoption of a name is one thing. The adoption of a magnitude is a very much more serious matter, and there are a great many serious considerations coming in. One one-hundredth of the present unit may be a convenient quantity for some. For others, another fraction may be a more convenient quantity, and there are different views to be taken of it, and I think those things ought notto be hurried.

THE PRESIDENT:—It seems to me also that the unit as adopted should harmonize with the other practical units—the ohm, volt, ampere and so on, so that in computation it should not be necessary to use a multiplier in connection with the unit of self-induction.

MR. CROCKER:—That very harmonizing with the units already determined is just the reason why the farad has such an ungainly value. I think that if the farad had been made a millionth of its present value, in spite of its not agreeing with the volt and coulomb, it would have been very much more convenient. Not one man in ten thousand who uses the micro-farad knows or cares whether it agrees with the volt or the coulomb. The farad is simply that capacity which will hold a coulomb, at one volt pressure. That requires an almost infinite condenser. If it had been fixed at the capacity which would hold a thousandth of a coulomb, at a thousandth of a volt pressure, then it would be just a microfarad. I think that in practical units, the first thing to do is to have them of convenient size. Their derivation must take care of itself. Of course the value must be definite; and

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we must know what it means. But it need not be based upon a ratio of 1 to 1. For one time that we have to derive it, we have to use it a thousand times, perhaps ten thousand. So that I think that practical units determined in the future should be convenient units, even though they are not derived from one volt and one ohm. Let them be derived from a tenth of an ohm or a volt, or a thousandth, if necessary, to make them convenient. This same question will come up very soon before electricians in regard to magnetic units. It is already coming up. It is recommended by Mr. Fleming to call one hundred million C. G. S. units of magnetic induction; that is one hundred million lines of force a "gilb." Now, one hundred million lines of force is a field produced by ten thousand square centimetres of cast-iron saturated. Ten thousand square centimetres is one metre square; that is, a square metre of cast-iron will produce one "gilb" when it is saturated. Now that is too large a unit, for the same reason that Dr. Bell has already stated—that every practical value would be a fraction. Dr. Fleming throws the "gilb" aside and begins right off with the "micro-gilb," and then he will probably get fractions of the "micro-gilb." In fact he uses one-tenth of a "micro-gilb." Now that is not a practical unit. I think that the units decided in the future should surely be made convenient. I would suggest that the resolution be adopted as read, with the additional clause that a Committee be appointed to determine the best and most convenient practical value for the "henry."

Mr. F. L. Pope:—It seems to me that the ultimate disposition we ought to make of this matter is to refer it to the International Electrical Conference, with our recommendation that the name "henry" be given to the practical unit of self-induction and our recommendation of a certain value. It does not seem to me that we can settle this thing all by ourselves. The rest would like at least to be consulted about it. I think if it were referred to them in that way there is very little doubt they could adopt it.

Mr. Crocker:—In regard to Mr Pope's remarks, there is a great deal of force in what he says, but the language of the resolution, I think, covers it. It says "that in our opinion it is proper that so and so should be done," which is a modest way of putting it. Then "that this Institute will gladly co-operate with other bodies in this country and abroad to secure its general adoption." If in addition to this Mr. Pope thinks we ought to say that the Institute recommends to the next International Congress of electricians that this unit be adopted by it, I see no objection to it Would you put that in as an amendment?

Mr. F. L. Pope:—Yes, I will make that amendment and I think we can take action on that to-night.

Mr. Phelps:—The matter before the house now, as I understand it is the adoption of this resolution as it stands, is it not?

The President:—Unless this other motion is seconded.

Mr. Crocker:—I accept the amendment.

Mr. Phelps:—The amendment is to what effect?

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THE PRESIDENT:—That it be referred to the International Congress or whatever body may be appointed to represent the International matters in regard to electricity.

MR. CROCKER:—The next International Congress.

MR. PHELPS:—That amendment I understand is accepted by the mover of the resolution so as to become a part of it.

THE PRESIDENT:—If the seconder agrees to that it may be counted part of the original resolution, if the house does not object to it.

MR. PHELPS:—Then I would offer a further amendment that a Committee of five be appointed by the Chairman to consider a proper magnitude for the unit "henry" and to make recommendations upon that subject to the next meeting.

(The motion was seconded.)

MR. CROCKER:—I accept that amendment.

THE PRESIDENT:—Is there any objection to its being incorporated as part of the original motion? If not it will be so incorporated. The motion is that we adopt this resolution which was read here in its printed form with the addition that we recommend its adoption to the next International Congress of Electricians and that a Committee of five be appointed to consider the best magnitude for the unit and to make recommendations and report at the next meeting. I believe we understand how the resolution reads. Those in favor of the resolution as stated please make it manifest by saying aye—contrary minds—no. It is carried unanimously.

DR. BELL:—Before taking an adjournment I would like to ask in behalf of the National Electric Light Association, for a little aid from the American Institute of Electrical Engineers. I chance to be the Chairman of the Committee of the National Electric Light Association to fix upon some definite classification of the lighting power of incandescent lamps. In other words, to determine what we should call a standard sixteen candle power lamp. A committee to straighten out the nomenclature of lamps was appointed at the last meeting of the National Electric Light Association, and feeling as I do the difficulty of the problem and the necessity of having it as thoroughly considered as possible, I would like to ask the appointment of a committee of three by the chair from this Institute to co-operate with the committee in that work. I offer the following:

*Resolved.*—That a committee of three be appointed to represent the American Institute of Electrical Engineers, in conference with a committee already appointed by the National Electric Light Association to fix upon a definite classification of the lighting power of incandescent lamps.

MR. CROCKER:—I would question whether that comes within our jurisdiction. That is purely a commercial question and we have never done much in that direction. But if the National Electric Light Association, which is especially interested in that subject, ask our co-operation, I certainly see no objection to giving it. But I think we better deliberate before we do go into purely commercial questions.

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MR. PHELPS:—I wish to second Dr. Bell's motion and to say that I do not quite see the force of Mr. Crocker's point in regard to the irrelevancy of that topic to our work. I do not see why the Institute of Electrical Engineers might not properly have a word to say as to standards of lighting as well as standards of resistance or any other electrical matter, and as we have the request virtually from the National Electric Light Association—that is to say from the Chairman of one of its committees—I think it is but proper that we should lend a hand in that work. Therefore I second the motion.

DR. GEYER:—I think it is not out of our province to help to determine what a sixteen candle-power lamp is, especially as we have been asked.

THE SECRETARY:—One of the difficulties in settling upon standards is getting different bodies to unite upon them and it appears to me that this is a move in the right direction, because if the National Electric Light Association and the American Institute of Electrical Engineers work together and settle this question, it will have more weight than if either one undertook it separately.

MR. DOBBIE:—It seems to me that the question would simply resolve itself into a standard of light.

THE PRESIDENT:—Those in favor of the resolution to appoint a Committee to consider the classification of the lighting power of incandescent lamps will please make it manifest by saying aye: those opposed no. It is carried.

MR. MARTIN:—Was that the exact shape of the recommendation? I was present at the meeting at Cape May, and I did not quite understand that to be the shape of it. I understood it to include arc-lighting as well as incandescent. I may be wrong.

DR. BELL:—The Committee was appointed to consider only incandescent lamps. Of course that includes series incandescent lamps burned on arc circuits. The National Electric Light Association felt that it was undertaking quite too severe a task to straighten out the arc-lamps before disposing of the incandescent.

THE PRESIDENT:—How is this committee to be appointed?

SEVERAL MEMBERS:—By the chair.

THE PRESIDENT:—Then if you will allow me, I will appoint on the Incandescent Lamp Committee, Dr. Nichols, Dr. Duncan and Mr. Howell, and on the Committee for the consideration of the value of the "henry," Mr. Crocker. Dr. Geyer, Dr. Bell. Mr. Colby, and Mr. Phelps. Is there any further business?

On motion of Mr. Phelps the meeting adjourned.

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# AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

## Special Meeting, October 21st, 1890.

The meeting was called to order by President Anthony at 8.20 P.M.

The Secretary read the names of the newly elected associate members.

The Secretary:—The next business is the report of the Committee to determine the value of the "henry"; and the revision of the preliminary report of the wiring table committee is also to be acted upon.

Mr. Francis B. Crocker:—I can report for both committees. As I said at the last meeting, the reference of these matters to committees would probably involve a delay of several months. I have tried to have several meetings, without very much success. but we have about half done the work, I should say, and probably by next meeting we will be able to report the result in finished form. The question of the value of the "henry" is rather an important one, and if we are going to recommend a value different from that of the quadrant we want to be perfectly sure that we are right and that it will fit the requirements of practice. So I report progress for both committees.

The President: (Prof. W. A. Anthony)—The first paper for the evening will be on "Investigation of the Stanley Alternate Current Arc Dynamo," by W. B. Tobey and G. H. Walbridge.

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*A paper read at the 50th Meeting of the American Institute of Electrical Engineers, New York, October 21st, 1890, President W. A. Anthony in the chair.*

# INVESTIGATION OF THE STANLEY ALTERNATE CURRENT ARC DYNAMO.

BY W. B. TOBEY AND G. H. WALBRIDGE.

BEFORE entering directly upon the subject to be presented this evening, *i. e.*, the investigation of the Stanley alternate current arc dynamo, it may be well to give a brief description of that new and extremely novel type of machine. Descriptions of it have been given in some of the electrical papers during the past spring, but some here may not recall its general mechanical construction. The dynamo is manufactured and sold by the Westinghouse Electric Company under patents granted to Mr. Wm. Stanley, Jr., the inventor. Mr. Albert Schmid, superintendent of the Westinghouse Electric Company's shops, deserves much credit for perfecting the machine in detail, and to him is largely due its success commercially. In general appearance it closely resembles the Westinghouse alternate current constant potential dynamo, which has become so familiar to all. In fact, the frame, pole pieces, field windings, etc., for any given size machine are identical, whether for constant current or constant potential. The distinguishing feature between them lies wholly in the form and winding of the armatures. Figs. 12 and 13, showing diagrammatically half sections of the machine, will aid us in a description of the armature, which is built up of thin iron plates stamped in the form shown. It will be observed that a number of cores corresponding to the number of poles of the dynamo project radially from the armature, and from the sides of each core project overlapping lugs. The armature coils are not of the original "pancake," or oblong flat coil type, placed on the periphery of the armature, but are quite thick and placed around the core projections. The overlapping lugs serve the double pur-

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pose of preventing the coils from slipping off the cores and also aid in the regulation of the machine. All the armature coils are connected in series and the terminals connected to the two collector rings, upon which bear the brushes furnishing current to the line. The field coils are also in series, so connected that the poles presented to the armature are of alternate polarity. The terminals of the field go directly to a small shunt wound exciter. Thus it is seen that the machine consists simply of an even number of field coils, corresponding to the number of poles on the machine, joined in series, and an equal number of armature coils also joined in series. That from such a simple combination of coils without any external regulating device, an almost constant current is obtained for all loads, from short circuit to

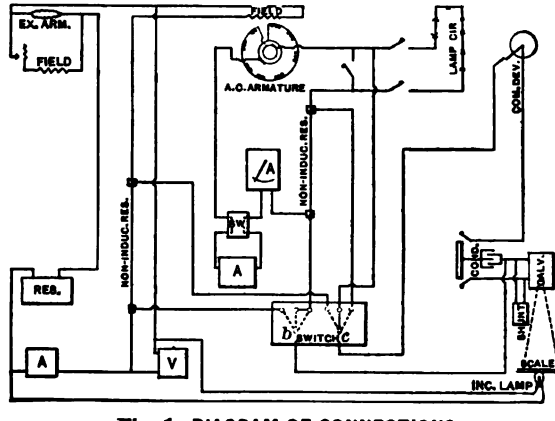


*Fig. 1.*—DIAGRAM OF CONNECTIONS.
A, A, A. Ammeters; V. Voltmeter.

the maximum output of the machine, seems incredible, but such is the case.

Through the kindness of Mr. Stanley, a complete 40-light plant was sent the writers at Cornell University, at which institution we were then students. Later, the Westinghouse Company made the University a gift of the entire plant. It has been our aim to show how the regulation takes place; also to determine the actual electrical output of the machine, and from the later and the corresponding dynamometer readings, to calculate the efficiency of the dynamo.

The alternator was mounted on a Brackett cradle dynamometer calibrated to read in watts direct at 1000 revolutions, the speed at which we were running.

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The general method has been to obtain instantaneous values of E. M. F., arc and exciter currents at a sufficient number of points to indicate by curves the performance of the dynamo at every part of a revolution. For this purpose runs were taken with the dynamo at short circuit and with loads of 5, 10, etc., up to 40 lamps. The dynamo was run under normal conditions, viz , at a speed of 1000 revolutions and with such excitation as to cause an output of approximately 10 amperes. For obtaining values of E. M. F. at low loads, pressure wires were run from the terminals of the dynamo and for larger loads were taken from around 10 lamps. At all points where instantaneous values of E. M. F. were taken, corresponding values of arc and field, or exciter currents

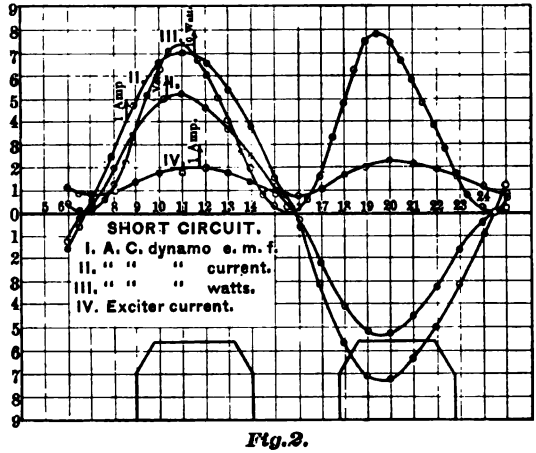


*Fig. 2.*

were obtained by "fall of potential" method. Pressure wires were brought from the terminals of each of two non-inductive resistances of german silver wire placed in arc and field circuits. (See Fig. 1.) These resistances being constant, any pressure around the terminals corresponded to a certain current. The terminals of the three pairs of pressure wires were connected to the contacts of the triple-throw switch, so that by placing the switch on any pair of contacts desired, those terminals could be put in circuit with a line in which was a condenser and the revolving contact or commutating device by means of which the condenser was charged. The revolving contact used was similar to the one described in detail by Prof. Ryan in his paper on "Transformers," read before the Institute last December.[1] It

1. See Transactions of the American Institute of Electrical Engineers, Vol. vii., p. 1.

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consists essentially of a knife-edge of steel fastened by a wooden clamp to the collector end of the armature, and revolving with it through a circle of about eight inches diameter. The centre of the knife-edge was in line with the centre of one of the armature coils. Upon a frame at the same end of the armature was held a wooden semi-circle, upon the periphery of which was a paper scale, divided to millimeters. At the centre of the semi-circle was pivoted an arm carrying a brushholder in which was a steel spring. The brushholder was so adjusted that the revolving knife edge made contact with the spring several times per second. The arm carrying this spring could be clamped wherever desired,

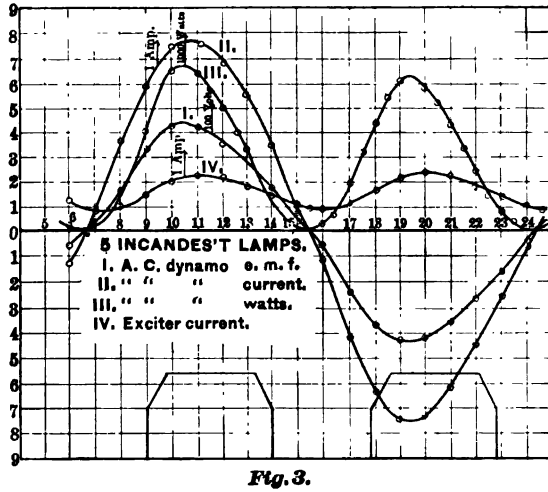


*Fig. 3.*

and its position designated by means of a pointer over the scale.[2] Thus, the condenser, placed in series, could be brought to the same difference of potential that existed between the spring and the knife-edge. The arc circuit was, as shown by the diagram of connections, Fig. 1, taken from one brush directly to a Westinghouse ammeter through a switch, by means of which a Thomson balance, or gravity ammeter could be put in circuit when desired. From the Westinghouse ammeter the current was taken through the non-inductive resistance to the dynamo short circuiting switch, where the other terminal of the machine was directly connected. The exciter current was measured by a Ryan gravity ammeter, and a Hartmann and Braun type voltmeter

2. Much trouble experienced by other investigators in this line, due to breaking of the spring, was entirely obviated by us by putting a piece of thin rubber packing above the spring where it was clamped in the brushholder.

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indicated the potential around the terminals of the field. The arm of the commutating device being clamped at some desired position, the spring was adjusted so that the revolving knife-edge made contact, then the switch was thrown on any one of the three pairs of terminals, for the circuits of which we wished to obtain instantaneous values. The half microfarad condenser was so connected that by closing a key it would be charged. Opening this key and closing one in circuit with the galvanometer, sent the charge through the galvanometer and the throw was noted.

The galvanometer used was 5000 ohms resistance, and consisted of the coil of a Sir Wm. Thomson marine galvanometer, in which was suspended a small, concave mirror, having several

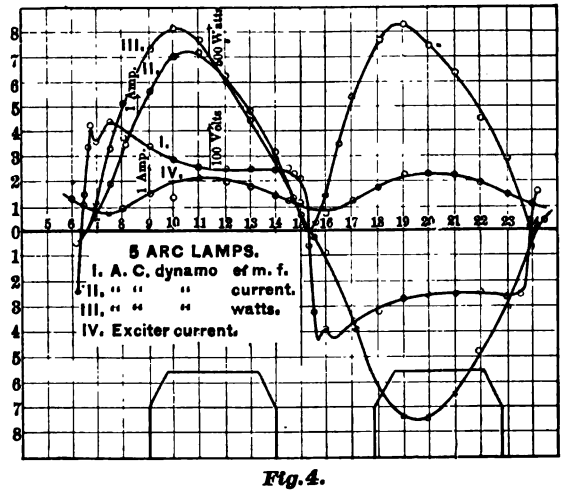


*Fig. 4.*

very small magnets constituting the needle, fastened on the back. The controller was a large horse-shoe magnet. A simple wooden frame supported the coil. A narrow slit in a screen, behind which stood an incandescent lamp, allowed an image of part of the filament to fall on the galvanometer mirror and be reflected back to the screen, on which was a graduated scale. By placing a resistance box in shunt around the galvanometer, the throw of the needle was reduced when it was desired to read the arc E. M. F. When current readings were taken, the whole charge of the condenser was passed through the galvanometer. The galvanometer was calibrated for E. M. F. by putting the condenser and a standard potential instrument in multiple around the terminals of a storage battery giving about 120 volts. Readings were then taken

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of the voltage, and the corresponding throw of the needle was noted. The calibrations of currents were made by running the exciter alone and passing the current through both of the non-inductive resistances, determining its amount by an ammeter, and observing the corresponding throw of the galvanometer needle for each non-inductive resistance.

So much for a description of the dynamo, the instruments and the methods used. We now come to that which is of most interest, viz., the results obtained. In order that the curves may be more easily followed we will give a brief general explanation of them.

The figures on the zero line, always commencing with 5, cor-

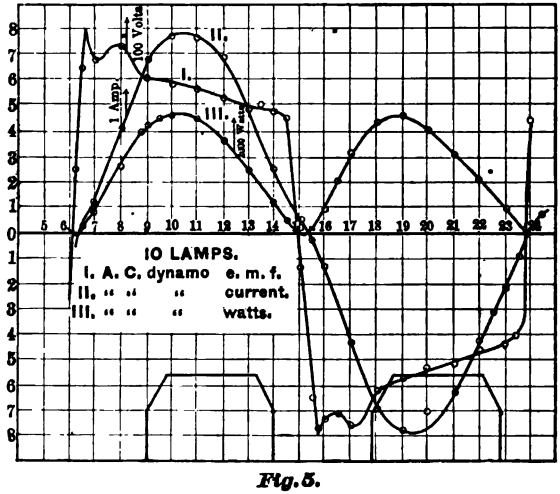


*Fig. 5.*

respond to the divisions on the scale of the wooden semi-circle, a part of the commutating device. Under each plate of curves will be seen two rectangular figures, representing pole pieces, which show the relative position of the curves with respect to the poles. From each curve projects a vertical arrow, always equal to one or two divisions, and its value marked near it. In all curves the direction or motion of the armature relatively to the poles is from left to right.

Fig. 2 represents the performance of the machine at short circuit. The curves of E. M. F. and current both approach sine curves; the current rising almost in unison with the E. M. F., there being no perceptible lag. The curve of exciter current in

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this, as in all cases, exhibits a wavy form. Fig. 12 shows the position of the armature relatively to the poles when the E. M. F. is zero and the machine running on short circuit.

Fig. 4, representing the curves for a load of five arc lamps, shows a radical change in the E. M. F., which now approaches more nearly to the form of a rectangle than a sine curve, and immediately after passing the zeros exhibits very sharp peaks. In this case the current continues to rise after the E. M. F. has begun to fall, and also lags slightly with respect to it. A shifting of the zeros has also taken place. Comparing this E. M. F. curve with that for short circuit it is seen that the first zero shown occurs at about 6.35 instead of 6.85. The curves for all loads of

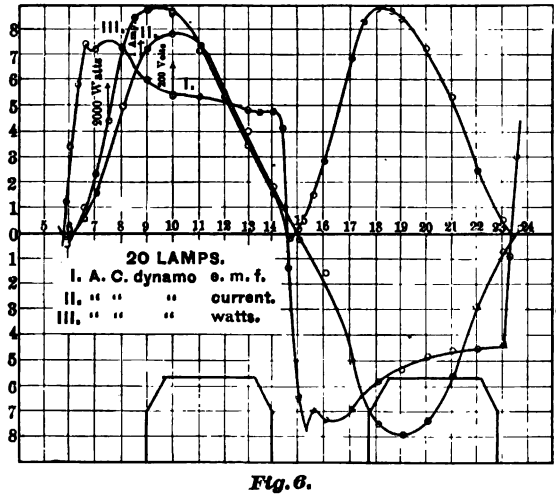


*Fig. 6.*

arc lamps are quite similar in form. as will be seen by referring to Figs. 5, 6, 7 and 8. As the load is increased, however, the zeros occur earlier with respect to the poles, and the current lag increases slightly. The efficiency curve, Fig. 9, tells the story of the dynamo from a commercial point of view, reaching as it does an efficiency of between 93 per cent. and 94 per cent. at full load while at half load it is 92 per cent.

A most interesting set of curves is shown in Fig. 10, giving a comparison of the forms and values of E. M. F. for 40, 30; 20, and 10 lamps, their position with respect to the poles, and also the position of the zeros of E M. F. at short circuit.

Figs. 13 and 12 show respectively the positions of the armature relatively to the poles for full load and short circuit.

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An apparently remarkable feature of the machine is that it may be short circuited when running at full load, without the slightest injury, and it may be run at short circuit indefinitely.

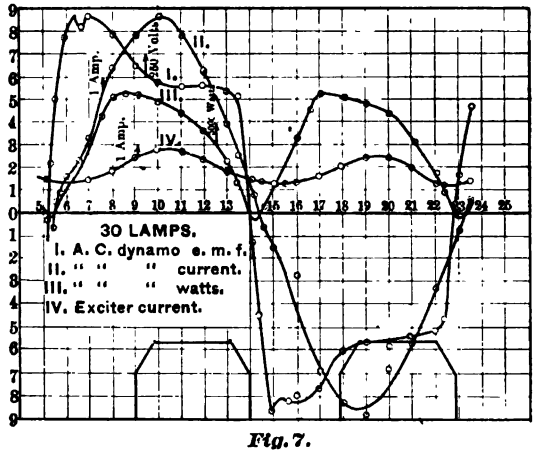


*Fig. 7.*

That the machine regulates with great rapidity is proven by the fact that upon short circuiting it, the ammeter indicates but a slight increase of current. The peculiar form of the E. M. F. curve for arc lamps led us, so far as time would permit, to an investigation of the cause, to ascertain which the following runs were taken:

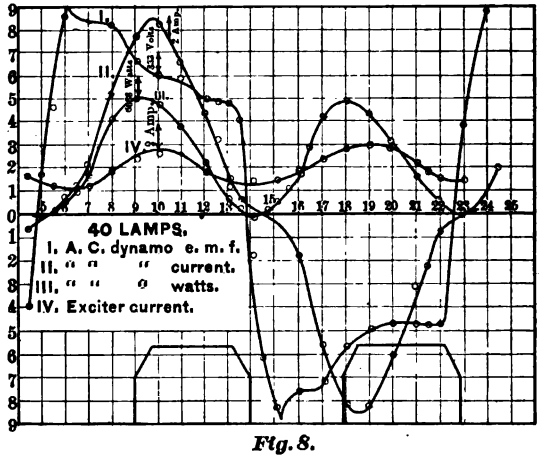


*Fig. 8.*

First, with a non-inductive resistance of five large incandescent lamps, but no arcs in circuit; each lamp consuming about the same amount of energy as an arc lamp. Second, with noth

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ing but an inductive resistance, consisting of a solenoid having 440 turns of No. 10 wire. The curves in both cases were similar and approached sine curves, proving the rectangular form to be

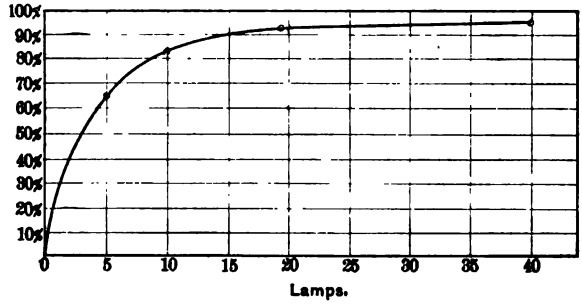


*Fig. 9.*—EFFICIENCY CURVE.

due entirely to the action of the arc. Fig. 3 shows the curves obtained from the load of incandescent lamps. To more fully determine this action with no other resistance in circuit, an arrangement was made whereby an arc could be regulated by hand with the aid of a hot wire voltmeter. We took no curve for a single lamp under normal conditions with which to compare the one taken in the above manner; but the latter (see Fig. 11) has very high and abrupt elevations of E. M. F. immediately before and after passing the zeros. The theory advanced to explain

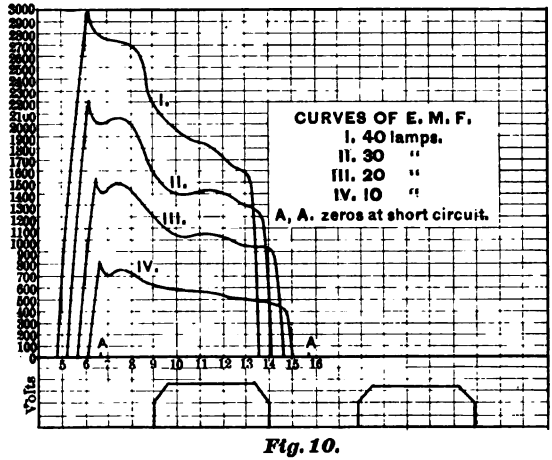


*Fig. 10.*

the high point of E. M. F. in all the arc curves is, that when the arc breaks, the rush of cold air adding resistance to the circuit, prevents the arc forming again until the potential has risen to a

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point considerably higher than that required to maintain an arc once formed. To test this we attempted to heat an arc by means of an alcohol blast, and thus prevent, in a measure, the rush of cold air. This means of heating proved inadequate, so that the results were not all that could be desired. As before stated, we had no one-lamp curve with which to compare it, but as compared with the one lamp regulated by hand, the sharp corners of E. M. F. were much modified. It is not certain, however, whether this was due to the action of the lamp regulating coils, or to the action of the flame. The current curve in all cases approaches a sine curve in form, but is always slightly steeper on the left or front side; direction of rotation being from left to right. Although the current lag is practically nothing at short cir-

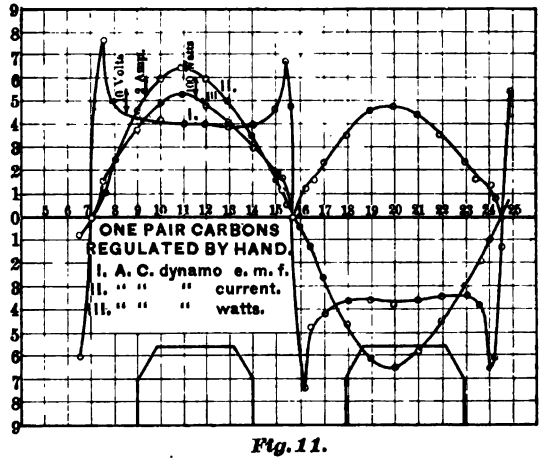


*Fig. 11.*

cuit, or for any load except arc lamps, it increases slowly as arc lamps are added. For 40 lamps it is about 4½ per cent. of the time of an alternation. The wavy form of the exciter current is probably caused by the variable resistance of the magnetic circuit, due to the projecting cores and lugs of the armature as they approach and recede from the poles. The values of E. M. F. and current were found by taking the square root of the mean square of 36 ordinates of a curve, representing a complete circle. Although the current lag was very small, the product of the values of current and E. M. F. obtained as above did not give the watts. The watts were obtained by plotting a curve, the points of which were the products of the instantaneous values of E. M. F. and current; then integrating by a planimeter. Dividing the value

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of the watts thus obtained by the current, we obtained a value of the E. M. F. which was usually about seven volts lower per lamp than the corresponding value obtained from the square root of

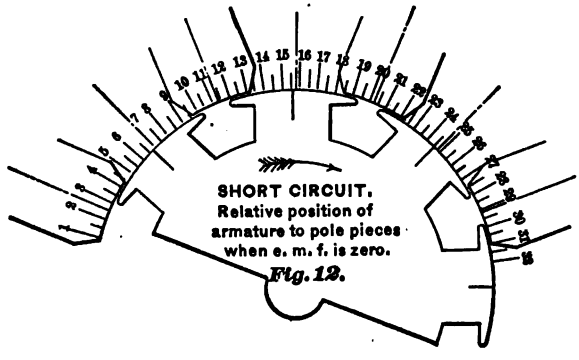

*Fig. 12.*

the mean square. This difference was no doubt due to the extremely high values of the E. M. F. when the current was very low, as the negative work was negligible. To distinguish between the two values we have called the one obtained from the square root of the mean square, the "actual" E. M. F. while the one obtained by the second method has been called the "effective" E. M. F., it alone being effective in doing work on the circuit.

It is very much of a question in our minds as to whether the square root of the mean square, obtained from the rectangular E. M. F. curves for arc lamps, gives the actual E. M. F., but for the

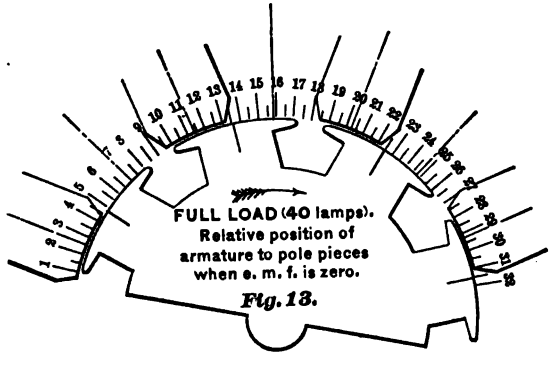

*Fig. 13.*

lack of a better term, the values thus obtained have been called the actual E. M. F's.

For arc current values we have assumed the square root of the

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mean square to be correct, and if not actually the case, they are certainly very close approximations, as the current curves are practically sine curves. The exact values of E. M. F. or current are of little consequence, however, except as a matter of interest, since the electrical output in watts is known, this alone being required to determine the efficiency.

In conclusion we can simply state that our investigations have shown, that the dynamo, aside from being very efficient and of most excellent regulation, is, as stated at the beginning, an extremely novel and interesting type of machine.

TABLE OF DATA.

| | $\sqrt{\text{Mean sq. of E. M. F.}}$ | Volts per lamp "actual." | $\sqrt{\text{Mean sq. of Current.}}$ | Volts per lamp "effective." | Mean watts electrical. | Watts excitation. | Mean watts by dynamometer. | Efficiency. |
|---|---|---|---|---|---|---|---|---|
| Short Circuit. | 3.53 | | 9.78 | | 35 | 155 | 1780 | |
| 5Incandescent. | 289. | 57.8 | 10.3? | 59.8 | 3060 | 158 | 3900 | 75.3% |
| 5 Arc. | 285. | 57. | 9.98 | 50. | 2500 | 165 | 3584 | 66.6% |
| 10 Arc. | | | 10.7 | 53.3 | 5700 | 190 | 6630 | 83.5% |
| 20 Arc. | 1100 | 55. | 10.36 | 48.3 | 10000 | 190 | 10680 | 92.3% |
| 30 Arc. | | | | | | 204 | 12120 | |
| 40 Arc. | | | 9.82 | 41. | 16000 | 240 | 16950 | 93.2% |
| 1 pr. carbons. | 42 | 42. | 8.86 | 35.5 | 314 | | | |

THE PRESIDENT:—As the paper of Mr. Reid applies in the same direction, that will be read before discussion is called for. The next paper will then be "A New Method of Analyzing Armature Reactions, applied to the Stanley Arc Light Alternating Current Machine."

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# A NEW METHOD OF ANALYZING THE MAGNETIC REACTIONS OF ARMATURES APPLIED TO THE STANLEY ARC-LIGHT ALTERNATING CURRENT MACHINE.

BY THORBURN REID.

This analysis is a result of looking at an old and well-known phenemenon from a new point of view, and is merely a development of the principle of the magnetic circuit a little further than has heretofore been usual. Hopkinson, I find, has used much the same method in his analysis of the transformer, and seems vaguely to have foreseen its application to dynamos; if I may judge from a part of a sentence which I ran across in one of his articles a few days ago, this same principle has been discussed at some length in the English electrical journals lately, but I am not aware that any analysis has been attempted by means of it.

By this conception dynamos are considered to consist of a magnetic circuit composed partly of iron (or steel) and partly of air, one part being at rest and the other in motion (generally rotary). Magnetism is induced in this circuit by means of two or more coils of wire carrying an electric current, wound around some part or parts of the circuit. One or more coils may be wound on the fixed part of the circuit and one or more on the moving part, and the magnetism induced will be that due to the sum of all the magneto-motive forces in all the coils, divided by the sum of all the magnetic resistances. The magneto-motive forces in the fixed coils are generally approximately constant, except where they are varied for purposes of regulation. In the movable coils, however, the M. M. F. is generally variable. In direct current machines its effect on the total flux around the magnetic circuit is also almost inappreciable, chiefly for the reason that it acts almost at right angles to the magnetic circuit. In alternating current machines,

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however, it is quite considerable, and is generally taken into account, but attributed to the self-induction of the armature. The connection between the counter M. M. F.; as it may be called, of the armature and its self-induction will be brought out more fully in a subsequent part of this paper.

To simplify our conceptions we will assume a two pole dynamo with one coil on the armature, as shown in Fig. 1. Referring to the diagram, Fig. 2,

Let $\overline{ON} = N$, represent the magnetic induction through the armature due to the field in magnitude and direction.

Let $\overline{CC'}$ represent the position of the armature coil at that instant.

Let $\overline{OA} = A$, at right angles to $\overline{CC'}$, represent the magnetic induction due to the armature coil at that instant.

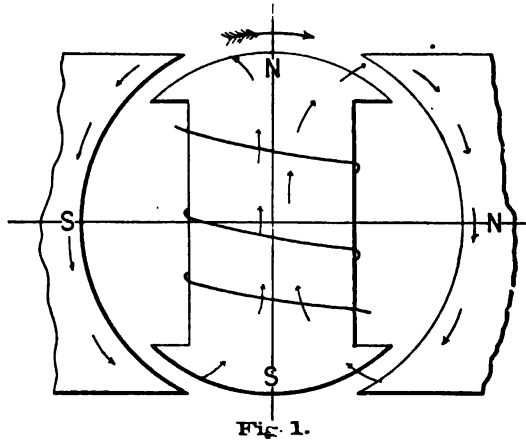


Fig. 1.

Let $\overline{PP}$, at right anges to the field lines, be the neutral line.

Let $POC' = \theta$ be the angle through which the coil has moved from its neutral position.

By completing the parallelogram, and thus compounding the two magnetizations $N$ and $A$, we obtain $M = \overline{OR}$ as the resultant magnetic induction through the armature coil in amount and direction at that instant, and $\overline{QQ'}$, at right angles to $\overline{OR}$, as the neutral line with reference to this resultant magnetization. Then $QOC$ $(= \sigma)$ is the angle through which the coil has turned from this new neutral line.

Let the angle $NOR$ $(= ORA) = \alpha$. We are to deduce the value of $M$ from the known quantities $N$, $A$, and the angle $\theta$. In the triangle $ROA$, $RO$ is perpendicular to $\overline{OQ}$ and $\overline{OA}$ is perpendicular to $OC$; therefore the angle $ROA = QOC = \alpha$.

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Also $\overline{OA}$ is perpendicular to $\overline{OC}$ and $\overline{AR}$ is perpendicular to $\overline{OP}$; therefore $\overline{OAR} = \overline{COP} = 180° - \theta$.

From trigonometry we have:—

$$\frac{M}{\sin(180° - \theta)} = \frac{V}{\sin\sigma} = \frac{A}{\sin\alpha};$$

or

$$\frac{M}{\sin\theta} = \frac{N}{\sin\sigma} = \frac{A}{\sin(\theta - \sigma)} \qquad (1)$$

therefore

$$N\sin(\theta - \sigma) = A\sin\sigma.$$

Expanding $\sin(\theta - \sigma)$, dividing by $\cos\sigma$ and solving for $\tan\sigma$, we have

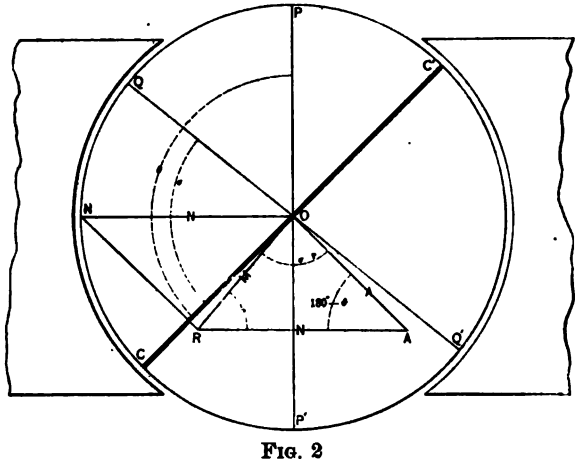


FIG. 2

$$\tan\sigma = \frac{N\sin\theta}{N\cos\theta + A} \qquad (2)$$

whence by trigonometry

$$\cos\sigma = \frac{N\cos\theta + A}{\sqrt{N^2 + 2AN\cos\theta + A^2}} \qquad (3)$$

$$\sin\sigma = \frac{N\sin\theta}{\sqrt{N^2 + 2AN\cos\theta + A^2}} \qquad (4)$$

Therefore from equation (1)

$$M = N\frac{\sin\theta}{\sin\sigma} = \sqrt{N^2 + 2AN\cos\theta + A^2} \qquad (5)$$

This last expression gives us the actual value of the induction

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through the armature coil at that instant in terms of the field strength, the armature strength and the angle $\theta$ through which the coil has been turned from the position perpendicular to the field lines. The direction of this resultant magnetization is along $\overline{OR}$, and the neutral line has been shifted from $\overline{OP}$ to $\overline{OQ}$ and the number of lines actually passing through the coils is $M \cos \sigma$.

From equations (3) and (5) we obtain $M \cos \sigma = N \cos \theta + A$.

The E. M. F. at any instant is then

$$E = -\frac{d}{dt}\left\{ S N \cos \frac{2 \pi t}{T} + S A \right\} \tag{6}$$

where $S$ is the number of turns in the coil; $t$ is the time which has elapsed since the coil passed the position $\overline{OP}$, and $T$ is the time of one revolution.

Therefore

$$E = \frac{2 \pi S N}{T} \sin \frac{2 \pi t}{T} - S \frac{d A}{d t} \tag{7}$$

The armature magnetization, $A$ depends on the number of turns in the coil, on the current flowing through it, and on the magnetic resistance offered to its lines of force; or

$$A = \frac{S i}{\rho} \tag{8}$$

where $\rho$ to the magnetic resistance, and $i$ the instantaneous value of the current.

Letting $\frac{S^2}{\rho} = L$, dividing through by $R$ the resistance in the main circuit, and collecting the terms, we have

$$\frac{di}{dt} + \frac{R}{L} i = \frac{2 \pi S N}{L T} \sin 2 \pi \frac{t}{T} \tag{9}$$

Let

$$\frac{2 \pi S N}{L T} = a, \frac{2 \pi}{T} = p, \text{ and } \frac{R}{L} = b,$$

and we have

$$\frac{di}{dt} + b i = a \sin pt \tag{10}$$

a differential equation which must be integrated.

The equation may reduced to the following form

$$i = e^{-bt} \int a \sin pt \, e^{bt} \, dt \tag{11}$$

which may be integrated by parts thus

$$i = ae^{-bt} \int e^{bt} \sin pt \, dt.$$

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Let $u = \sin pt$ and $dv = e^{bt}\,dt$; then $du = p \cos pt\,dt$ and $v = \frac{1}{b}e^{bt}$; $\int u\,dv = \frac{1}{b}e^{bt}\sin pt - \int \frac{1}{b}e^{bt}\,p\cos pt\,dt$;

$$i = \frac{a}{b}\sin pt - \frac{ap}{b}e^{-bt}\int e^{bt}\cos pt\,dt.$$

Let $u = \cos pt$, and $dv = e^{bt}\,dt$; then $du = -p\sin pt\,dt$, and $v = \frac{1}{b}e^{bt}$; $\int u\,dv = \frac{1}{b}e^{bt}\cos pt + \int \frac{1}{b}e^{bt}\,p\sin pt\,dt$;

therefore $i = \frac{a}{b}\sin pt - \frac{ap}{b^2}\cos pt - \frac{p^2}{b^2}i$; or

$$i = \frac{a}{\sqrt{p^2+b^2}}\left\{\frac{b}{\sqrt{p^2+b^2}}\sin pt - \frac{p}{\sqrt{p^2+b^2}}\cos pt\right\}$$

Let $\tan^{-1}\varphi = \frac{p}{b}$. Then substituting for $a$, $b$ and $p$ their values we have

$$i = \frac{2\pi SN}{\sqrt{R^2T^2+4\pi^2L^2}}\sin(\theta-\varphi) \qquad (12)$$

where $\varphi$ is the angle of a lag, or the angle by which the effective E. M. F. lags behind the impressed E. M. F.

This is the instantaneous value of the current at any instant. Since the average value of the square of the sine of any angle is $\frac{1}{2}$, we have, calling C the square root of the average square of the current:

$$C = \frac{\sqrt{2}\,\pi SN}{\sqrt{R^2T^2+4\pi^2L^2}} \qquad (13)$$

$$E = \frac{\sqrt{2}\,\pi SNR}{\sqrt{R^2T^2+4\pi^2L^2}} \qquad (14)$$

You will no doubt have already recognized this equation as the ordinary equation of the alternating current dynamo, *when the self-induction of the armature coils is taken into account*,. This analysis so far has taken no account of the self-induction in the armature coil. There has, however, been introduced into the discussion a factor not generally treated in this connection, namely, the counter M. M. F. of the coil. This factor occurs in the equation as the expression for which I have used the letter $L$. $L$ is ordi-

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narily used to denote the co-efficient of self-induction, and I chose it for that very reason. The connecting-link is shown by the value given to $L$ in our equation; namely $\frac{S^2}{\rho}$.

We shall now show that $L$, the co-efficient of self-induction of a coil, is equal to the square of the number of turns in the coil, divided by the magnetic resistance of the circuit, through which the lines of force of the current flowing in the coil must travel. There are several ways of getting at a definition of $L$ and perhaps the simplest is the following:

The counter E. M. F. of self-induction of a coil, in which a varying current is flowing, is $L\frac{di}{dt}$ where $\frac{di}{dt}$ is the rate of change of the current at the instant considered; or, more simply, if the current is changing at a constant rate, it is the number of amperes through which the current is increasing or decreasing in a second. If the current is changing at the rate of one ampere in a second, $\frac{di}{dt}$ becomes unity and $L\frac{di}{dt}$ becomes equal to $L$. Therefore $L$ represents the counter E. M. F. of self-induction of a coil, in which the current is changing at the rate of one ampere in a second.

Now selecting suitable units, the number of lines of force which will be sent around a magnetic circuit of magnetic resistance $\rho$ by a current of one ampere flowing through a coil of $S$ turns, will be $\frac{S}{\rho}$. Therefore if the current is increasing at the rate of one ampere per second, $\frac{S}{\rho}$ lines of force will be inserted or taken out of the coil in a second, and the E. M. F. set up will be $\frac{S}{\rho} \times S = \frac{S^2}{\rho}$; but, since the current is changing at the rate of one ampere per second, the E. M. F. set up $= L$. Therefore $L = \frac{S^2}{\rho}$.

These equations (13 and 14) might have been arrived at a little differently by resolving the counter-magneto-motive-force of the coil parallel to the induction due to the field, and then considering the comparative values of the resistances through the inside of the coil and around the outside; but this method is more complicated than the one I have chosen, and a little consideration will show that it is precisely the same thing, merely looked at from a different point of view.

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Now let us see how this equation must be modified to suit the conditions obtaining in the Stanley alternating arc machine. This machine is of the multipolar type, with the coils laid flat on the armature core. It differs from the ordinary Westinghouse alternating machine mainly in the facts that each coil consists of a large number of turns, and is laid in longitudinal grooves in the armature core in such a manner as to be almost entirely surrounded by iron, and that the number of alternations per second is large. As a result of this arrangement the machine maintains a nearly constant current throughout wide variations of resistance and speed.

To explain this phenomenon we will use equation (13), first substituting for $L$ its value, $\frac{S^2}{\rho}$, and we have

$$C = \frac{\sqrt{2}\ \pi\ S\ N}{\sqrt{R^2\ T^2 + 4\ \pi^2\ \frac{S^4}{\rho^2}}} \qquad (15)$$

Since there is a large number of turns in the armature coil, $S$ is very large and $S^4$ correspondingly larger. Then, since the coil is almost completely surrounded by iron, $\rho$ is very small, and accordingly $\frac{S^4}{\rho^2}$ is exceedingly large. Then, since the number of alternations is very large, $T$, the time of one alternation, is a very small fraction, and, therefore, $R^2\ T^2$ may be neglected as compared with $4\ \pi^2\ \frac{S^4}{\rho^2}$. Neglecting this term then and reducing, our equation becomes.

$$C = \frac{N\ \rho}{\sqrt{2}\ S} \qquad (16)$$

This equation shows that $C$ is dependent on the magnetic induction through the coil due to the field, on $\rho$ the magnetic resistance to the lines of force of the coil, and on $S$, the number of turns in the coil. *Resistance and speed are conspicuous by their absence.*

We must remember, however, that if $R$ and $T$ are increased sufficiently in value, $R^2\ T^2$ will cease to be negligible as compared with $4\ \pi^2\ \frac{S^4}{\rho^2}$, and therefore, every increase in $R$ will increase the denominator of equation (15) and $C$ will decrease.

If, therefore, we fix the limits between which the current may change, while the resistance in the main current is changing from

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its lowest to its highest value, we may determine the speed below which the machine must not run. Any increase of the speed above this point merely tends to lessen the fluctuation of the current between the highest and lowest resistances. Again, any increase in the speed above this point will widen the range throughout which the resistance may vary, without the fluctuation in the current passing the prescribed limit. $R$ will have its lowest value when the armature is short-circuited, and will then equal the resistance of the armature coils, and the current will be at its maximum value The minimum value of the current then being fixed, the maximum value of $R$ will depend on the value of $R^2\ T^2$, as compared with $4\ \pi^2 \frac{S^4}{\rho^2}$ or $R$ (maximum) may vary inversely with $T$, or directly as the number of alternations per second.

Returning now to equation (16) we see that $C$ varies directly as $N$ (the field is separately excited) and $N$ varies directly as the exciting current. Therefore any increase in the magnetizing current will correspondingly increase the main current. This is in fact the method by which the main current is brought to its proper value. The machine is short-circuited and the main current brought to its proper value by varying the magnetizing current. The main current will then remain practically constant throughout the prescribed range of resistance.

Secondly, the current varies directly as $\rho$. This, too, has been shown to be true, for in one of the first machines built the coils were wound in cylindrical logitudinal holes in the armature core so that they were entirely surrounded by iron, and as a result the current obtained was too small to be measured. Longitudinal slots were then cut in the armature core so as to increase $\rho$, and by widening these slots to the proper amount, the desired current was obtained.

Finally $C$ varies inversely as $S$, the number of turns in the armature coil. That is, the more turns in the armature coil the less the current delivered. This, too, was found to be true in the experimental stage of the work. But it must be remembered that S must not be made so small that the term $4\ \pi^2 \frac{S^2}{\rho^2}$ becomes comparable with $R^2\ T^2$. We may perhaps obtain a simple conception of the reaction by slightly changing the form of our equation We may write equation (13) thus.

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$$C = \frac{\sqrt{2}\,\pi\,S\,N}{R\,T\sqrt{1+\frac{4\,\pi^2\,L^2}{R^2\,T^2}}} = \frac{\sqrt{2}\,\pi\,S\,N}{R\,T\,\sqrt{1+\tan^2\varphi}} \qquad (17)$$

where $\varphi$ is the angle of lag.

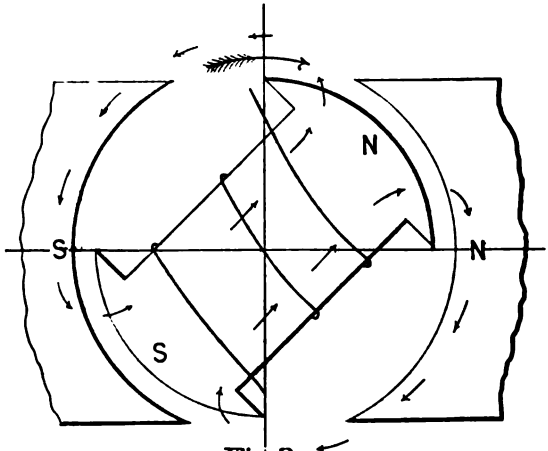


Fig. 3.

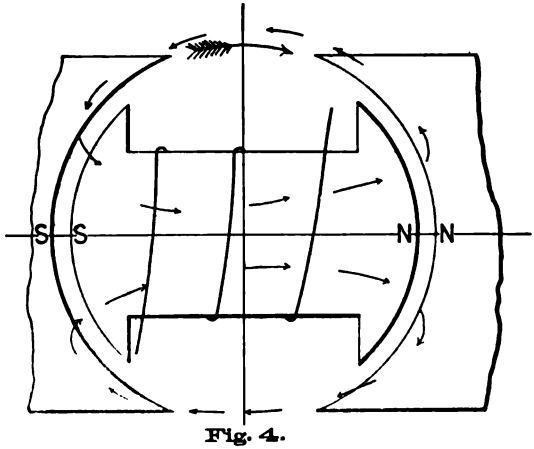


Fig. 4.

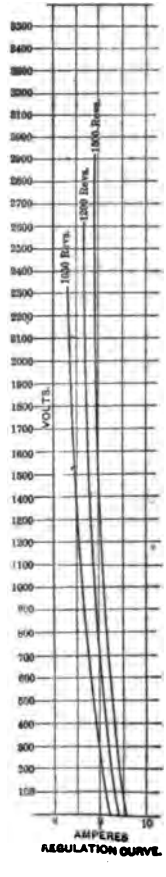


Fig. 5.

Neglecting the term 1, under the radial sign, we have

$$C = \frac{\sqrt{2}\,\pi\,S\,N}{R\,T\tan\varphi} \qquad (18)$$

tan $\varphi$ varies inversely as $R\,T$, and therefore the product of tan $\varphi$ and $R\,T$ in the denominator remains constant. Referring to Fig. 1, and remembering that $\varphi$ is the angle by which the effective E. M. F. lags behind the impressed E. M. F., we observe that if there

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is no lag in the effective E. M. F., or, the current will reach its maximum value when the coil is in the position shown in Fig. 1; and therefore the largest possible number of lines will flow through the coil and will be taken out of it during the revolution. As $\varphi$ increases, the current is delayed in reaching its maximum value, until the coil has passed the position shown in Fig. 1, and when $\varphi$ is nearly 90° the coil will have nearly attained the position shown in Fig. 4 before the current reaches its maximum value; but in this position the M. M. F. of the coil almost exactly opposes that of the field, thus largely reducing the number of field lines which will pass through the coil. As $\varphi$ increases, the E. M. F. decreases. Then we have: a decrease in $R$ tends to increase the current, but a decrease in $R$ tends to increase $\varphi$, which, in turn, decreases the effective E. M. F. and reduces the current. $\varphi$ must be nearly 90° so that the demagnetizing effect of the coil may vary inversely as $R$, which it will not do if $\varphi$ is small. The result may be viewed in still another way; we may write our equation thus,

$$C = \frac{\sqrt{2}\,\pi\,S\,N\,n}{\sqrt{R^2 + 4\,\pi^2\,L^2\,n^2}} \qquad (19)$$

where $n$ is the number of complete waves per second. The numerator of this fraction will then represent the E. M. F., which would be set up in the coil, if there were no self-induction. The denominator consists of the ohmic resistance $R$, and of another term due to self-induction, which is equivalent to an added resistance and has been called the inductance. This quantity $2\,\pi\,L\,n$ multiplied by $C$ will equal the counter E. M. F. of self-induction of the coil. As long, then, as the inductance or induction resistance of the coil is very large as compared with the ohmic resistance, any change in the ohmic resistance will only very slightly affect the total resistance, which is the sum of the two.

Let us now consider what light these equations will throw on the question of designing the machine. The problem is to obtain a current of the desired strength and constancy, with the least expenditure of energy and at the least expense, and the quantities with which we may work to obtain this result are $N\,S\,\rho$ (or $L$) and $T$. We see immediately that it is advantageous to make $T$ as small as mechanical considerations will allow, since the smaller $T$ is, the more constant will the current be throughout the range, or the wider the range the resistance may have without causing the current to vary below the prescribed limit. This points then to a multiplicity of poles, or high speed, or both.

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$N$, on the other hand, should be as large as possible, for the output of the machine varies directly with that factor, and its increase does not at all affect the fluctuation of the current. $S$. again, should be as small as it can be made without affecting too much the regulation of the machine.

$\rho$ is the one indeterminate quantity in this equation. It is almost impossible to calculate its value beforehand to any reasonable degree of accuracy, for several reasons. The magnetic circuit of which it is the resistance, varies in cross-section through-

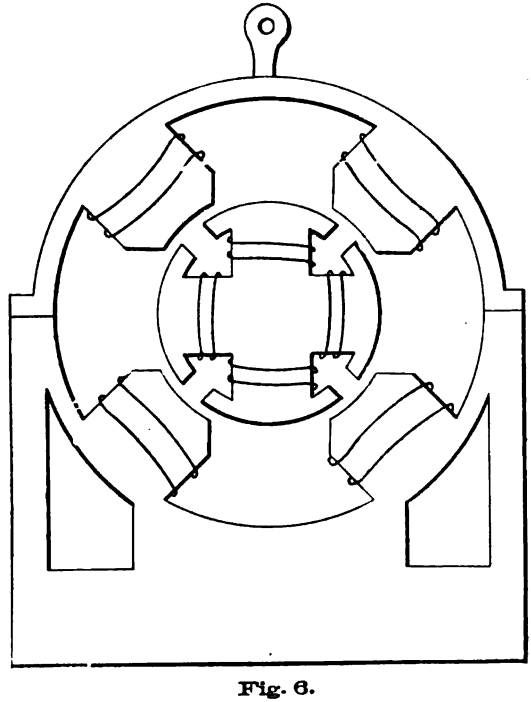

Fig. 6.

out its whole length, and this variation is not uniform but has several points of discontinuity. Furthermore, $\rho$ varies during the revolution of the armature, for when the armature pole is half way between two field poles, part of the path of the lines of force is through the field pole, and when the armature pole is opposite the field pole, that same part of the path of the lines of force will be made up of the air gap between the two field poles, and $\rho$ will be much increased. An approximate value might be obtained by determining $L$ with the armature in different posi-

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tions and taking an average of the values thus obtained; but if in actual practice the iron is worked anywhere near the saturation point, this method would be of doubtful utility, unless the currents used in determining $L$ were the same as those used in practice.

Probably the best method for practical work would be by means of a curve of current and E. M. F., where, all the terms being known except $\rho$ and probably $N$, we can obtain $n\rho$ from one point on the curve, and both $\rho$ and $N$ from two points. This method, while it would probably not give us very accurate values of these two terms, would be of value for purposes of comparison, so that by means of a large number of determinations we might obtain data which would be very useful in designing future machines.

Another useful thing to know is what is the highest value which the E. M. F. will attain on open circuit. This may be obtained from equation (14) thus: Dividing both numerator and denominator by $R$ and neglecting the second term under the radical sign (since $R$ is infinite on open circuit) we have,

$$E = \frac{\sqrt{2}\,\pi\,S\,N}{\sqrt{T^2 + \frac{4\,\pi^2\,L^2}{R^2}}} = \sqrt{2}\,\pi\,S\,N\,n \qquad (20)$$

where $n$ is the number of complete periods per second.

This E. M. F. will of course be very high, since there are very many turns in the armature coil, and $n$, the number of periods per second, is very large. As a consequence of this, if the machine is allowed to run on open circuit, the armature insulation will soon break down, thus producing a ground which will speedily burn out the machine.

The following is the complete formula where all the terms are expressed in practical units.

$$C = \frac{\sqrt{2}\,\pi\,S\,N}{10\sqrt{10^{15}\,R^2\,T^2 + 12.768^2\,\pi^2\,S^4\,\mu^2\,\frac{A^2}{l^2}}} \qquad (21)$$

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## Discussion.

The President:—I think the members of the Institute will agree with me that these are two exceedingly interesting papers. We should be very glad to have a full discussion.

Mr. William Stanley, Jr.:—Mr. President, the papers that have been read this evening refer to the regulation of a dynamo with which there is no external appliance to control the current. In applying an alternating potential to a circuit, there are two kinds of opposition to current flow. One kind is offered by the resistance of the circuit, determinate in the dimensions of the circuit, and the specific material of which it is composed, while the other is the opposition due to the shape of the circuit, that which we ordinarily call the self-induction of the circuit. Now the relation of these two oppositions to the flow of current is not exactly the same. The resistance of the circuit opposes the flow of the circuit at the instant the potential is applied. The counter-electro-motive force of self-induction first delays the flow of current and then urges it on, and the time that elapses between the application of a given potential to a circuit and the flow of current corresponding to any particular value of the potential, is determinable by the ratio of the value of the self-induction to that of the resistance. Now in this machine that these gentlemen have spoken of, we may consider that all that part of the circuit which is inside of the machine, viz., the armature coils, represents the self-induction part of the circuit. This portion therefore tends to delay the flow of the current for awhile, and afterwards to push it on. All that part of the circuit external to the machine may be considered to represent the resistance portion of the circuit. Now it is evident we cannot change the number of turns of wire, or very well the number of revolutions of the machine when running; consequently we cannot change the value of the self-induction in circuit and therefore the ratio of the self-induction to the resistance. The change of this ratio—by simply short-circuiting such arc-lamps as we may wish to turn out, changes the time of appearance of the current. It lets the armature of the machine get a little further ahead when one lamp is burning, when the maximum value of the current in the armature occurs; that is, it allows the armature pole to come up in front of the field pole, as shown in Fig. 10, and to oppose the field pole, (the magnetization in the armature being directly opposite to that in the field) it keeps the lines of the field magnetism from passing through the armature. This effect is very beautifully shown by winding on the two armature circuits, one an arc circuit, and another a few turns of wire connected with the voltmeter, both wound upon the same tooth. If the machine be short circuited, the magnetism is, as it were, blown out, and no potential is found upon the supplemental circuit. The whole regulation of the machine is due then to the fact that, as shown in Fig. 10, the time of the current flow has advanced, as we see

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intricate nature. (Laughter.) And thus it appeares to me that we should handle mathematics with a great deal of delicacy, care and judgment, and use them in a mixed multitude only when we have to, the highest function of a technical paper being to instruct.

Referring for one moment to alternating machines *per se*, although it is a little perhaps out of the exact track of the papers before us, and the discussions which should properly follow them. I may say that there is quite a prevalent impression in the land, and quite largely, among gentlemen who suppose themselves to be electricians. that alternating currents used in electric lighting date back only to the time when Gaulard and Gibbs employed them to excite the primary of an induction coil or transformer for incandescent lighting. Within the last two weeks I have heard it gravely asserted by such a gentleman, that the first time an alternating machine was ever used in lighting was on that occasion. It was of very little use to tell him, (for he would not have believed me if I told him and swore to it on a stack of bibles,) that the first machine ever used for lighting was an alternating machine, and the first currents used were for arc lights without commutation. Nevertheless it is true that the Von Malderen or Alliance machine was an alternating machine and achieved better success in arc lighting than the machine subsequently made by Holmes in England in which the currents were commutated. I would not, of course, venture to compare the highly organized machine of to-day, such as the one of which we have heard this evening, with the very crude alternating current machines of past time, for they were simply the magnetic machine of Clark and Saxton multiplied indefinitely; that is, a number of the electro-magnets placed upon a frame were whirled around, the entire effect being due to the multiplication. Whereas in the machine of to-day we have principles which have been learned by experience, and greatest and most valuable of all we have the principle of the magnetic circuit. Nevertheless I have thought it not out of place to call the attention of the Institute to the fact that alternating machines *per se* were old; that alternating currents in electric lighting are not new, and that advance has been made chiefly on the lines of improving and doing on well defined principles, things which have been inferiorly done before our time.

I might mention in conclusion that the Jablochkoff candle was in its time operated also by alternating currents for the reason that if it had not been, the positive carbon would have burned much faster than the other. Therefore, as many of you will remember, instead of using the Gramme machine with its continuous current, the Gramme machine was used to separately excite an alternator, which in turn was used to furnish current for the candles.

MR. E. T. BIRDSALL:—There is one point in the paper of Messrs. Tobey and Walbridge about which I would like to ask a

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question, and that is in regard to the efficiency. They say that the efficiency varies between 93 and 94 per cent. Now the question I would like to ask is, how the efficiency was obtained from the curves. The reader said that it did not matter whether the volts were taken by the mean square process or by the watt curve—you got watts all the same. I would also like to ask whether the efficiency takes into account the power used by the exciter?

MR. TOBEY :—In reply to the gentleman, speaking of the two values of E. M. F. and efficiency, the former was obtained first, from the square root of the mean square; second, by the taking the watt curve, the points of which were plotted from values obtained from the instantaneous values of current and E. M. F. These gave the instantaneous values of watts at periods; then integrating the curve we obtained the output in watts. In this manner we obtained the value of the watts without determining either the E. M. F. or current. Dividing the watts by the current gave us the second value of E. M. F. and current, but we separated them only as a matter of interest.

The values of efficiency include the excitation. The method of getting these efficiences was to divide the watts electrical output by the sum of the watts by dynamometer, plus watts excitation.

MR. CHARLES STEINMETZ :—In looking through the equations given here by Mr. Reid I see the magnetism of the field, called $N$, is supposed to be constant. Therefore, the magneto-motive-force of the field magnetism, that is the exciting current is supposed to be constant, too. But that will hardly ever be so, because of the induction, which the varying magnetism produces in the field circuit.

Now here in the diagram given by Mr. Tobey and Mr. Walbridge I see the instantaneous values of the exciting current varying by more than 50%. Therefore it would follow that the field magnetism is varying in the same manner in that kind of alternating generator, and I could not think the equations to be complete, if the field magnetism is supposed to be constant. To complete the equations, there ought to be added to the term $N$, another factor, *f. i.* of the form;

$$1 - \varepsilon \sin^2 (\theta - \omega),$$

where $\varepsilon N$ is the amplitude of the variations of exciting current, $\omega$ its angle of lag.

Furthermore here I see the magnetism $A$ is supposed to be proportional to the magneto-motive force over the magnetic resistance. And this magnetic resistance is supposed to be constant. I think it would make a certain difference in these equations if, also, this assumption of the constancy of magnetic resistance should be abandoned, as not being quite true. And therefore I think, also, here another term ought to be added; but if this should be done, these equations become so complicated indeed, that I hardly think it possible to integrate them. (Laughter.)

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must produce fluctuation when the course of the lines of force is changed, just the same as a change in ohmic resistance in an ordinary circuit would produce fluctuations in the current. Hence, if we take a small coil of wire forming by flexible conductors a closed circuit with a telephone, and place this coil near the field of a dynamo electric machine in a suitable relation to the field, the oscillation of the lines of force, due to this change of magnetic distribution each time there is a commutation, causes the induction of a minute alternating current in this coil whose number of periods or frequency is equal to the number of commutations per second, and causing the telephone to emit a note of corresponding pitch. The paper which I read at the time, showed further how one could trace the course of the lines of force leaking from the magnetic field of the machine in this way by means of the telephone, because if the oscillation is in the same plane as the exploring coil there will be no noise in the telephone and if it is at right angles to the plane of the exploring coil the noise will be loudest.

I have also had occasion to study that fluctuation in a more perceptible way, on a larger scale, in connection with the older form of machines formerly in use, old shuttle wound armatures of the Siemens type. When they are used for producing continuous currents, we get, strictly speaking, not a continuous current, but a series of alternated impulses. We have really a large impulse in one direction followed by a smaller impulse in the opposite direction, in each case, so that the current is only relatively continuous in spite of the commutation. Now I have seen machines of that type where by putting another coil around the magnetic field an alternating current could be obtained which could be used for producing electric light, working transformers or anything of that kind, showing that in this case the oscillations or the wavy action taking place in consequence of the reactions of the armature on the magnetic field, were sufficient to determine a motion of a magnitude adequate to produce the induction of a current in a suitable circuit.

I join with the other gentlemen in expressing regret that we could not get sooner the substance of the able paper read by Mr. Thorburn Reid, in order that we might have the opportunity to digest it and come here better prepared to discuss it. I must say that I, myself, while I could not follow it entirely, have been able to find in it a great many points which are, to say the least, very novel in their method of treatment. I do not deprecate in the least the presentation of papers of that character before this body, because, while I grant that they have a great deal of theoretical value, I feel that they have even more practical value than many of us imagine or are willing to concede. The very circumstance, for instance, that we are enabled to get a clearer perception of the phenomenon of inductance is one which will contribute greatly to the progress we look for in the uses and applica-

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tions of the alternating current. I think that the day is coming when we shall be able to express the phenomenon of inductance which is to-day a perplexing and confusing one even to the mathematician, with as little effort and to understand it with as much ease as is now the case with the phenomena and the relations of non-inductive resistances. And in this connection I wish to invite those who study these matters from the mathematical standpoint to consider in connection with their treatment the fact that the elasticity of the lines of force themselves, is a reactionary factor of importance in the phenomena taking place while currents are being induced by the cutting of lines of force.

In expressing inductance we have to introduce the notion of velocity since the E. M. F due to self-induction varies with the rate at which lines of magnetic force are cut. Now the notion of velocity must involve the consideration of the fact that the lines of force themselves are not passive during the operation of being cut; that they may yield one way; that there is a certain tension produced by the reaction of the current which would make them give way, as Mr. Stanley has so well said. Now in that case the velocity would evidently be affected and the rate of cutting would be reduced; while in the rebound they would fall back, and thereby increase the relative velocity or rate of cutting.

DR. M. I. PUPIN:—There is an interesting point which I would like to discuss in a few words and that is, the peculiar form of the curve which expresses the electromotive force. When arc lamps are introduced in the circuit it is evident that the form of the curve is entirely different from the form which we obtain when there are incandescent lamps in it. Mr. Tobey suggests that it is probably due to the change of resistance brought about by the cold air which is cooling off the carbon points, and the experiment which he devised to test this, seemed to prove his suggestion. But there is another way of looking on this matter, and that is this: we know that the current is conveyed between the carbon points by means of luminous carbon particles. The resistance between the carbon points depends not only on the contact between the two carbon points, but also on the amount of the luminous carbon particles which pass between the points. Now, the amount of these luminous carbon particles depends on the strength of the current, just as in electrolysis, the amount of an element deposited by the electric current. Therefore, the resistance will change with the current. When the current is zero the resistance will have a maximum. When the current is a maximum the resistance will be a minimum. Most of the resistance in the arc circuit is due to the resistance between the carbon points. These changes in the resistance of the whole circuit may therefore, be very considerable. In addition to that, we have, of course, changes due to the variation in the temperature of the carbon point. Now, Mr. Tobey says that they introduced the

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flame of an alcohol lamp between two points and observed that the sharp corners in the curve were modified—rounded off. But the flame is, comparatively speaking, a very good conductor of electricity, so that by putting a flame between the two carbon points, in order to prevent, as he intended, cold air from rushing in, he has introduced a good conductor there, and has prevented those large variations in resistance, and has thereby prevented sudden changes in the electromotive force.

There is another point which I would like to mention. A gentleman said to-night that it is very desirable to introduce magnetic resistance in the definition of self-induction, for the simple reason that in that case we would have something tangible, whereas the definition of self-induction as given by Neumann is a mathematical one and intangible. Well, I do not agree with that gentleman, for the simple reason that Neumann's integral for the co-efficient of self-induction represents a certain physical quantity which can be measured. It refers to the electro-magnetic energy of the field, and energy is the best conception to have. I do not know what the magnetic resistance is. I cannot imagine anything that would represent magnetic resistance, unless I establish first the relation between this quantity and the electro-magnetic energy. The integral of Neumann represents a certain amount of energy which we can measure in a great many ways. One of those ways, is simply to surround the conductor through which the lines of force run by means of a wire loop whose ends lead to a ballistic galvanometer, break the circuit, destroy that magnetic energy and have it appear as some other form of energy. It will appear in the surrounding wire as a current; the energy which this current represents is the physical meaning of self-induction, or co-efficient of self-induction, if you please. So that the integral, after all, is the best mathematical and practical definition of self-induction; and besides defining the quantity it also suggests to us a method of determining its numerical value.

The third point and the last one which I wish to mention is this: Mr. Reid assumed at first the magnetic resistance of the machine as constant, and assuming that, his equations are all perfectly correct until he gets to equation sixteen or seventeen in which he discusses the resistance $\rho$. Dr. Steinmetz remarked that if we introduced $\rho$ as a variable we would obtain a differential equation which is not integrable. I do not agree with him in this particular case, for the simple reason that $\rho$ will be a quantity which varies in a certain way and has two points of discontinuation during one revolution. It is a periodic function. It has the same period as the machine. In the second place the function has two points of discontinuity. We can represent every function of that sort by a series of sines and co-sines. But if we look at these curves here which Mr. Tobey obtained we see that these curves are practically sine curves; therefore, we have every reason to infer that the magnetic resistance will be a simple har-

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monic function and that this is equal to a constant plus a sine function. Of course if we should be unable to assume that $\rho$ is a simple harmonic function then I confess we would obtain an equation which would be very difficult to integrate. Not so in our case.

DR. CARY T. HUTCHINSON: I do not see how Mr. Reid's equations differ from the ordinary well-known forms based on the assumption of a sine curve variation and constant magnetic permeability.

Another point—in his paper he has given several diagrams of magnetic circuits and based certain explanations upon these dia grams. In Figs. 3 and 4, the lines of induction pass through the armature and back entirely by air. Where is the return part of the circuit? It is certainly not completed through the air as shown. Referring to the definition of the co-efficient of self-induction, is not one of the simplest definitions, the number of lines of induction enclosed by the circuit? This of course includes the case both of air and iron, and takes into account very plainly the reluctance.

Again, I do not see how the reluctance of the circuit can be a simple sine function for the reason that the air gap forms the largest part and is constant.

DR. PUPIN:—I did not say that it is the same sine function. I said magnetic resistance is a simple harmonic function. Of course, magnetic resistance is connected with self-induction. But it does not follow at all that the co-efficient of self-induction will be a simple sine function.

MR. STEINMETZ:—I concede that I did not yet try to integrate those equations. I only doubted their integrability because I several times tried to integrate such complicated expressions by explicit functions indeed, I mean, and I generally got left.

With regard to the magnetic resistance, I believe this term has come into general use, because it gives a very great advantage in numerical calculation, where absolute exactness is not needed, and you are allowed to suppose the magnetic resistance to be constant. But so soon as you enter deeper into the proceedings and try to take into consideration the variability of the term "magnetic resistance," then indeed the matter becomes very complicated, because you can hardly do anything else than define the term "magnetic resistance" as the quotient of magneto-motive force over magnetic current, or number of lines of force, and then the magnetic resistance becomes a very complicated function, which sometimes becomes infinite, too, because sometimes the magneto-motive force may become zero, when the magnetism is not zero, and the magnetic resistance for the same magneto-motive force can have all values from a certain minimum up to infinity, even can become zero. Therefore, in this case, you can not use the term "magnetic resistance" with any advantage, and we have to go back to the old and well-proved manner of mathematical calculation.

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MR. TOBEY:—The reason we used the galvanometer at the time we made these experiments was, that there was no suitable electrometer except one which was in use. We afterwards found that, had we used the electrometer we would not have been able to indicate the sudden changes of E. M. F. across the zero line, the throw of the electrometer always being in the same direction; consequently the very sudden changes from a positive to a negative value would not be definite.

DR. HUTCHINSON:—Dr. Duncan of Johns Hopkins University and two associates made some experiments of this kind nearly three years ago; these curves before me might almost be taken as tracings from some of theirs and the description of the method and apparatus used in obtaining them applies almost verbally to their method and apparatus. This is the more remarkable as neither in this paper nor in Prof. Ryan's read before the Institute some time ago and which was even closer to Dr. Duncan's than this one is—as both dealt with transformers—is there the slightest reference to their work. Their experiments were made on a Siemens dynamo using both open and closed circuit transformers. Nor did they find any difficulty in the direct use of a Thomson quadrant electrometer.

MR. REID:—I would like to add a little to the discussion of magnetic resistance by referring to some investigations I made a little while ago on a transformer. I calculated the lag of the transformer, taking the magnetic resistance as that, which we would have with the square root of the mean square of the current and found it entirely too great. Then taking the hysteresis as shown by Ewing's curves and calculating the work lost by hysteresis in the transformer, I found that the lag came out very nearly what was actually found in the transformer, so I had to assume that Ewing's curves were applicable to the transformer. Now if we plot our curves of magnetization by means of Ewing's curves, assuming that the current follows the *sin* law, we will get a curve of magnetization not at all like a *sin* curve. The side where the curve rises is almost vertical and it comes down again to the zero line much more gradually. The curve is almost a rectangle with rounded corners. If that is the case I do not see how we can get the co-efficient of self-induction as a *sin* function. The first investigation seems to show that hysteresis is present in the transformer and the second that the current cannot be a *sin* function if this is so. And yet experimentally the current appears to follow the *sin* law which would appear to show that the co-efficient of self-induction was a *sin* function.

THE PRESIDENT:—The time for our adjournment is considerably past. I do not like to stop a discussion so interesting as this is on so interesting a paper.

MR. TOBEY:—Before adjourning I would like to ask if some members here cannot throw some light on the subject which I brought forward, when I said it was a question in our minds as

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to whether or not the square root of the mean square of a rectangular curve, similar to our electromotive force curves, gave the actual E. M. F. We do not understand it, and would like to be enlightened by any one who has had experience in dealing with this form of curve. If the square root of the mean square does not give the actual electromotive force, how can it be obtained directly from the curve?

DR. HUTCHINSON:—Replying to the question as to the cause of the difference between the value calculated from the square root of the mean square and the observed values from the curve, the explanation is simply that the values calculated are based on the assumption of a sine curve, whereas the curves given are very different.

MR. T. C. MARTIN:—Before the notice of adjournment I would like to say on behalf of the committee on papers and meetings that, as Mr. Pope has said, it is our constant endeavor to get the papers here on time, and we have tried and tried in vain to have the papers brought to us sufficiently in advance to have them printed. I think I may say that we have now practically abandoned any serious effort in that direction. I would like to add that this is not the last opportunity at which any paper presented can be discussed. This is not a meeting for the conversion of the unrepentant. We can discuss these papers a month hence and any gentlemen has the privilege of rising on the floor and asking for an explanation or taking any paper which has been presented and offering any remarks on it. I would like to say also in regard to that matter that if we print the papers twice we put the Institute to a great deal of additional expense.

My business in rising Mr. Chairman, was not so much to make that explanation—it is by no means an apology, simply a statement—my object in rising is to present to your notice, and I hope your favorable consideration, a resolution which has been placed in our hands by our friend, Mr. Allen R. Foote, the Secretary of the National Electric Light Association and the special census agent for obtaining electrical statistics for the eleventh census. The resolution is as follows:—

"WHEREAS, Senator Hale, Chairman of the Senate Committee on Census, has introduced a Bill of which the following is a copy:—

A BILL.

TO AMEND AN ACT ENTITLED "AN ACT TO PROVIDE FOR TAKING THE ELEVENTH AND SUBSEQUENT CENSUS," APPROVED MARCH FIRST, EIGHTEEN HUNDRED AND EIGHTY-NINE.

BE IT ENACTED BY THE SENATE AND THE HOUSE OF REPRESENTIVES OF THE UNITED STATES OF AMERICA IN CONGRESS ASSEMBLED, That for the purpose of rendering the investigation of the electrical industries by the eleventh census thorough and complete in every detail, the Superintendent of the Census, under the direction of the Secretary of the Interior, is hereby authorized and directed to make such sub-divisions of the subject as may seem to him advisable, and to associate with the special agent now commissioned to investigate the manufacture of electrical apparatus and supplies and their uses, as special

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expert, the ablest person whose services can be secured to write the statement for each subdivision so made, subject to the supervision of said special agent; and the sum of fifty thousand dollars, or so much thereof as may be necessary, is hereby appropriated out of any money in the Treasury not otherwise appropriated.

"*Whereas*, it is the opinion of THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS that the enactment of this bill is not only desirable but of the highest importance to the industries and people of this country generally, therefore be it

"*Resolved*, that the proper officers of the INSTITUTE be authorized and directed to make such statements and representations to the Chairman of the Committee on Census of the United States Senate and House of Representatives, as in their judgment are necessary and pertinent, to assist in securing the action desired."

I might say that the National Electric Light Association has already taken action supporting this bill, which has been read twice and referred to the Committee on the Census. A similar resolution will be presented, and I have no doubt adopted by a large number of the electrical bodies throughout the country, and I think personally that it is the duty of the American Institute of Electrical Engineers to give its hearty support to such an investigation and report. I do not think that the electrical industries have the slighest objection to standing up and being counted. At the present time there is the utmost vagueness in regard to the electric interests of the country. In fact, if we take the oldest—the telegraph—there are no statistics to-day of the mileage of telegraph lines in this country except the Western Union. We want that information. A great deal of the work in the future absolutely depends upon it. Then I think that we would be perfectly satisfied with even a Porter census, especially with regard to the people that we are alleged to have killed. We want this information not only as persons who are practically engaged in electrical industries, but also as experts and electrical engineers, and I should be very glad indeed if this resolution meets the support of the meeting.

DR. SCHUYLER S. WHEELER:—I move that Mr. Martin's resolution be adopted.

(The motion was seconded.)

MR. R. W. POPE:—It does not appear to me that we ought to vote money out of our treasury—each of us being interested in the funds of the Government—without further consideration. I am sure this matter is a surprise to me. If we had a committee on the census we might refer it to them. It appears to me that we ought to give this matter careful attention. It is brought up at a late hour, and for my part I do not feel altogether like recommending an appropriation of this kind without thinking it over. This matter has been brought before this meeting to be sure, but we have had no notice of it and I do not think it has had a fair discussion. I would move that it be laid over until the next meeting for action

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MR. MARTIN:—I would like to say Mr. President, that there is certainly—although our friend Pope may be too busy to get around to it—there is certainly no lack of information on the subject. I have in my hand copies of a pamphlet of which several thousand have been distributed throughout the country, which was prepared under the authority of the National Electric Light Association and which gives a large amount of information as to what is actually contemplated. It even classifies the various subjects that it is proposed shall be taken up. A great many of those subjects will fall within our own province. I venture to hope that some of our own members will be specially selected as the gentlemen who shall prepare those subordinate and subsidiary reports which shall be placed in the hands of the special agent. The document in question was printed very largely in every one of the electrical papers in this country. I think Mr. Pope himself printed part of it.

MR. R. W. POPE:—Not as coming before this body for action.

MR. MARTIN: Not as coming before this body for action, no. This is the first time the resolution has been introduced. This is a matter which requires time and thought and attention. I thought it had received that. Congress does not meet until December and we can certainly take it up in November. In the meantime we shall see other bodies passing this resolution and I myself, as a member of the Institute, wish to see it take an active interest in the forefront in such a matter.

MR. GEO. M. PHELPS:—I want to say that I do not see any particular object to be gained by laying this over. On the face of it, all can understand it in two minutes. There is nothing to investigate about it. It is very plain and direct. We join with many others who have also been petitioning through members of Congress and otherwise to have that appropriation made. The object of that appropriation certainly cannot fail to have the interest of all members of this association. Electrical people certainly ought to be the very ones to put their shoulder to the wheel and get that thing carried through if possible. I do not think we shall be any better prepared in November to vote on this resolution than we are to-day, and the sooner, therefore we act upon it the better.

DR. W. E. GEYER:—I do not see what special right electricians have to ask Congress to make a special census for them. Manufacturers of all kinds might ask to have special censuses made in their departments and there would be no end of censuses asked for. Then it does not seem to me a dignified position for the Institute to petition Congress for this money especially when it is suggested that some of us might be the ones to get it.

THE PRESIDENT:—I did not understand that the motion to postpone the consideration of this question was seconded.

A MEMBER:—It was.

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THE PRESIDENT:—Then the motion is to postpone the consideration of this resolution until the next meeting.

The motion was lost.

THE PRESIDENT:—Now the question is on the original motion. I believe you understand what the motion is without my stating it.

MR. MARTIN:—I may say that our proposal has already had the approval of Congress to a certain extent, that body having listened to the bill twice. There is no intention to put any heavier duties on Mr. Pope than he now has. I can quite sympathize with his anticipations and apprehensions.

The resolutions were adopted and the meeting adjourned.

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# AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

## Discussion of the Revised Report of the Standard Wiring Table Committee.

The fifty-first meeting of the Institute was held at 12 West Thirty-first street, New York, November 18, 1890.

The meeting was called to order by the President, Prof. W. A. Anthony.

The President:—Have the Committee on the Standard Wiring Table anything to report to-night?

Mr. F. B. Crocker:—In accordance with the instructions of the meeting of the Institute held two months ago, the "Standard Wiring Table Committee" have amended their report. The report as amended stands as follows:

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# REPORT OF THE STANDARD WIRING TABLE COMMITTEE.

## Matthiessen's Standard of Resistance of Copper.

The Council of the American Institute of Electrical Engineers, at its regular monthly meeting held December 3d, 1889, appointed a Committee "To formulate and submit for approval a Standard Wiring Table for lighting and power purposes."

The Committee appointed consists of the following members of the Institute: Thomas P. Conant. Dr. Louis Duncan, Prof. Wm. E. Geyer, A. E. Kennelly, Geo. B. Prescott, Jr., E. Wilbur Rice, Jr, Prof. E. P. Roberts, Prof. Harris J. Ryan, William Stanley, Jr. Dr. Schuyler S. Wheeler and Francis B. Crocker, Chairman.

This action was taken by the Council with the object of overcoming or reducing the great confusion which now exists in regard to the standards and constants of electrical conductors.

At the first meeting of the Committee, held January 10, 1890, it was decided to confine the work for the present to the three subjects of Standard of Resistance, Temperature Co-efficient, and Safe Carrying Capacity of Copper, since these are of fundamental importance.

The subject of Matthiessen's Standard alone is so confused and involved, and the discrepancies in regard to it are so great between the best authorities, that the Committee has devoted its attention almost entirely to this subject up to the present time.

A very thorough investigation of Matthiessen's work has been made by a sub-committee, consisting of Prof. Wm. E. Geyer, George B. Prescott, Jr. and the Chairman, Francis B. Crocker, and the conclusion has been reached that the most correct and satisfactory "Matthiessen's Standard" and the one which we now

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recommend for general adoption is stated as follows: A soft copper wire one metre long and one millimetre in diameter ("metre-millimetre") has an electrical resistance of .02057 *B. A.* units at 0° centigrade.

From this the resistance of a soft copper wire one foot long and one-thousandth of an inch in diameter ("mil-foot") is found to be 9.720 *B. A.* units at 0° *C.*

In order to convert these values into legal ohms we may assume one *B. A.* unit to be equal to .9889 legal ohm, and the metre-millimetre value then becomes .02034 legal ohms, and the mil-foot value becomes 9.612 legal ohms.

The resistance of copper at temperature other than 0° centigrade may be determined by using Matthiessen's formula $C_t = C_0 (1 - .00387\ t + .000009009\ t^2)$ in which $C_t$ is the conductivity at the given temperature, $C_0$ is the conductivity at 0° and $t$ is the given temperature in degrees centigrade. It should be carefully noted, however, that this formula refers to *conductivity.* Therefore in order to apply it to resistance it is necessary to take the reciprocal and this should not be done by merely changing signs, which is not mathematically correct although usually given in that way. The correct modification of Matthiessen's formula when referred to resistance is

$$R_t \quad R_0 (1 + .00387\ t + .0000597\ t^2)$$

The sub-committee after careful consideration came to the conclusion that Matthiessen's "mile-standard" (one statute mile of copper wire $\frac{1}{76}$ inch in diameter has a resistance of 13.59 *B. A.* units at 15.5° *C*) is not the correct one, although very commonly used. Matthiessen himself did not place much confidence in this "mile-standard." The Committee, acting under instructions from a meeting of the Institute, held September, 16, 1890, has based all standards and values in this report upon soft or annealed copper, since its properties are reasonably constant and reliable. Whereas the Committee has purposely excluded from its recommendations all standards and values based upon hard copper although several were given by Matthiessen, because the hardness of copper is merely relative and the resistance of hard copper may vary between wide and uncertain limits depending upon the *degree* of hardness.

As to the fact often brought up that copper may be found which tests one or two per cent. higher conductivity or less resistance than Matthiessen's standard, we are of the opinion that

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this is no real objection provided the value of the standard is definite and generally accepted. A standard which is not the highest attainable value may even be considered an advantage, since the average commercial wires will approximate to it more closely.

Although we believe the standard we recommend will answer the purpose temporarily and probably permanently, nevertheless we think that if a thoroughly correct and complete redetermination of the standard resistance of copper could be accomplished, it would be a benefit to electrical science and industry. Favorable offers in this direction have already been received by this Committee from Johns Hopkins University, Cornell University and Columbia College, and it is likely that this redetermination may be undertaken.

The following statement of the most important and reliable figures and facts given by Matthiessen will serve to show the derivation of the standard which we recommend.

A hard-drawn copper wire 1 metre long weighing 1 gramme ("metre-gramme") has a resistance of .1469 *B. A.* units at the temperature of 0° centigrade.[1]

Matthiessen also gives the resistance of a hard-drawn copper wire 1 metre long and 1 millimetre in diameter ("metre-millimetre") as .02104 *B. A.* units at 0° *C.*[1]

This implies a specific gravity of 8.89 for the copper used by Matthiessen, but unfortunately he neglected to actually determine the specific gravity.

Matthiessen's figures for relative conducting power are:[2]

| | |
|---|---|
| Silver | 100 |
| Hard or unannealed copper | 99.95 |
| Soft or annealed copper | 102.21 |

From these the resistance of Matthiessen's hard copper is found to be 1.0226 times that of soft copper, therefore the resistance of a soft copper wire 1 metre long and 1 millimetre diameter ("metre-millimetre") is .02057 *B. A.* units at 0° *C.*, which is the standard we recommend.

From this the resistance of 1 cubic centimetre of soft copper is found to be .000001616 *B. A.* units at 0° *C.*

And the resistance of soft copper wire 1 foot long and .001 inch in diameter ("mil-foot") is 9.720 *B. A.* units at 0° *C.*

1 Philosophical Magazine, May 1865.

2 Philosophical Transactions, 1864.

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Taking one *B. A.* unit as .9889 legal ohm any of the above values may be converted into legal ohms To find the conductivity of copper at temperatures other than 0 ° Cent. Matthiessen's formula may be used, viz:

$$C_t = C_0 (1 - .00387\ t + .000009009\ t^2) \text{ or}$$
$$R_t = R_0 (1 + 00387\ t + .00000597\ t^2)$$

TABLE.

| Standard Resistance at 0° C. of | B. A. U. | Legal Ohms. |
|---|---|---|
| "Metre-Millimetre" Soft Copper.. ..... | .02057 | .02084 |
| "Cubic Centimetre" " " ..... .... | .000001616 | .000001598 |
| "Mil-Foot" " " ..... | 9.720 | 9.612 |

One mil-foot of soft copper at 10.22° *C* or 50.4° *F* has

| | | |
|---|---|---|
| Standard resistance of exactly .... ... .. ..... | 10 | legal ohms. |
| Same at 15.5° *C* or 59.9° *F*. ..... | 10.20 | " " |
| " " 23.9° *C* or 75° *F*..... .... ... ..... | 10.58 | " " |

F. B. CROCKER,
*Chairman.*

## Discussion.

Mr. Crocker:—This report is substantially what was presented before, except that we now exclude all reference to hard copper and confine the recommendations to soft copper; this is to avoid confusion and to avoid reference to hard copper, the resistance of which is a variable and indefinite matter. In other respects I think this report is exactly in accordance with the instructions of the September meeting.

The President:—You have heard the report, gentlemen. What will you do with it?

Mr. Jo. Stanford Brown:—I move that the report be adopted with thanks.

Dr. M. I. Pupin:—I second the motion.

Mr. R. W. Pope:—Would it be well to adopt it now as the official action of the Institute?

Mr. Mailloux:—I would like to amend by adding the words; "adopted and printed in the Transactions."

Mr. Brown:—I accept that amendment.

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THE PRESIDENT:—The motion is that the report be adopted and printed in the Transactions. Are there any remarks on the motion?

MR. R. W. POPE:—I rise to say, Mr. President, that the older societies are very conservative in regard to adopting anything of this kind and putting it forth as the official act of the body. They accept the reports and print them and let them go out, but they do not officially adopt them. I do not know whether there is any reason why they should not. I merely state that such is the practice. The same point came up at the recent Richmond meeting of the Mechanical Engineers in regard to a report on the tests of steam pumps, which was said to be a most excellent piece of committee work.

MR. BROWN:—I think that would be a wise thing to accept it in that shape—that is accept it though not adopt it as a society, yet have it printed in the minutes.

THE PRESIDENT:—I understand then that you make your motion to receive the report instead of adopting it?

MR BROWN:—Yes, sir, to receive it with thanks and have it printed in the Transactions.

MR. CROCKER:—I do not see that any useful end is to be subserved by simply shelving the report in this way. I do not think it is encouragement to future work, in this or any other direction. Of course the society ought to take action which is proper, and conservative, and to its best interests, but I should like to ask what will finally be the treatment of this report?

MR. E. T. BIRDSALL:—I think in matters of this kind it would be best to accept the report, cause it to be printed in pamphlet form and distributed among the members. Then, at the end of a certain time, say two or three months, the matter could be brought up again at a meeting and finally adopted and officially printed in the Transactions.

MR. GEORGE B. PRESCOTT, JR.:—It seems to me that this is a very simple question and one that the Institute could act on to-night. For a great number of years Matthiessen's standard, for the specific resistance of many metals including copper, has been universally accepted by electricians, and the actual tests that he made are duly recorded; but owing to the changes in value of various units that have been made from time to time, the text-books in recalculating these standards have adopted different values. The result is that although the electrical profession seem to be entirely satisfied to take Matthiessen's figures as a sufficiently accurate value for the resistance of pure copper, when they come to refer to the text-books for this figure, they find that different values are given. For that reason Matthiessen's standard has become meaningless, as there are a great many values for it current. Now the Institute recognized that it was very desirable that when this standard was referred to, a particular

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value should be understood. This Committee was appointed simply to determine, not the absolute resistance of chemically pure copper, but simply Matthiessen's value for it, and so avoid all confusion. Now this Committee have searched through Matthiessen's original papers and have ascertained what this value was that he determined. They found moreover, that even Matthiessen's work was not entirely satisfactory and that there is considerable question as to the accuracy of this value; but at the same time they have ascertained without question what the value is, and that they have given in this report. Now it certainly will save a great deal of trouble to the electrical profession generally to have some definite standard, and it seems to me that the Institute, if it approves of the Committee's labors can accept this value as being Matthiessen's standard for the specific resistance of copper.

MR. THOMAS D. LOCKWOOD:—I fear that the gentleman who spoke last has fallen into the error of believing that because he so thoroughly understands the subject, he being, as I understand, one of the Committee, and thoroughly conversant with it from one end to the other, that every member of this Institute is in the same fortunate position. It is no doubt a natural error for him or any one else to fall into. I listened with great attention to the reading of the report of the Committee, and I am free to say that while I have not the slightest doubt that the report will be adopted, I should consider it unwise to adopt it this evening. It is of such importance that it should certainly be printed, so that every gentleman connected with the Institute should have a chance to read it and make the matter his own as thoroughly as Mr. Prescott has made it his own. After it is printed the matter can very readily be brought up again and the members can vote upon it intelligently and I have no doubt will then adopt it.

With respect to Mr. Matthiessen; for a long time his figures were accepted as being conclusive. Perhaps the gentleman himself did not believe they were so conclusive, as I believe he ultimately shot himself. It is within the bounds of probability that electricians hereafter may, (quite unreasonably of course), entertain some doubts as to the figures now presented, and for this reason we should act carefully and intelligently, and I do not think we could act intelligently upon the report read to-night, because no matter how carefully we listen, or how persistently we listen, still the ideas, as they follow one another in rapid succession, in a measure obliterate those that have come before.

MR. MAILLOUX:—I would like to make the motion that the report be adopted, as well as printed.

THE PRESIDENT:—I understand that was the original motion, and unless the Institute consent to the change that will be the motion the Chair will put. The motion, after we have commenced discussion upon it should remain as it was originally put, unless the Institute consents to the change.

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MR. MAILLOUX:—That being the case I would state that I am in favor of the motion being put and passed as it was originally worded. The discussion reminds me somewhat of some of those works which are written on electrical engineering, and which though they embody the very best ability of their authors, are nevertheless by a kind of modesty on their part designated as elementary treatises only. On the same principle we have appointed a Committee, which, I think I can say contains the best material for the purpose to be found in this Institute. I have not had the pleasure of attending the meetings for some months, in fact almost a year, and I did not know much about this work or who constituted the Committee. When I heard the Chairman of the Committee read the list of members composing the Committee, I for one, felt that I would be perfectly willing to accept their views upon this matter and adopt any standard which they might give us. It is something more than an elementary treatise. Of course we all understand that the standard can only be a temporary thing at best In 1881, the Electrical Congress at Paris adopted a so-called legal resistance unit. In other words they defined the value—the length which a column of mercury of one square millimetre of section must have in order to constitute a legal ohm. Well, we have since found that this length is not right, and we have to-day a Continental value of the legal ohm, and a British value of the legal ohm which differ from each other by a small fraction; and later redeterminations of the ohm show that neither of them is correct, and that we must increase the length of the mercury column. Now I regard this Committee's work as merely a means of effecting a temporary compromise so that the practitioners may know what to adopt pending further investigation which will be made under the auspices of that Committee, or under the auspices of some other committee appointed by some other scientific body. There is no reason to doubt that before long we shall get at the bottom of facts relating to the specific resistance of copper, yet if meanwhile we can find something which enables us to get along and make our calculations with a reasonable degree of accuracy and consistency for all practical purposes, I think we ought to be satisfied. For that reason I think we ought not to hesitate to adopt a report which gives us what is probably the nearest to the truth as the facts now seem to warrant. When it becomes necessary to amend our table, I think that it will be done in a proper manner Therefore, I hope the report of the Committee will be adopted.

MR. BIRDSALL:—The last two or three sentences that Mr. Prescott uttered, convey just the idea of my former remarks. He said that if the remainder of the Institute were satisfied as well as he was with the report, then it would be adopted. The rest of the Institute, as Mr. Lockwood very aptly put it, are not as well

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satisfied as Mr. Prescott, because they are not as well versed in the subject. Therefore I would ask Mr. Brown if he would accept my first remarks as an amendment to his motion.

MR. LOCKWOOD:—I beg one moment's indulgence, Mr. Chairman, I do not like to speak twice upon the same subject. Somehow it seems to be implied that any such action as I advocate this evening would be disrespectful to the Committee. I beg to say that I yield to none in my respect for the Committee. I regard it, also, as being constituted of the best material we have. But if the report of the Committee is to be at once adopted, then I have to say that when the Committee was appointed it might as well have been decided to give them *carte blanche* and accept whatever report they chose to make. That is all.

MR. CROCKER:—If it is distinctly understood that this report is to be printed and submitted to the Institute, and in the course of a reasonable time the report is finally adopted, why then I offer no objections. I think the comments of the five hundred intelligent members of the Institute on a matter of this sort are very desirable.

MR. H. W. POPE:—Mr. Chairman, that was my idea in making the remark I did—that the report should be accepted and of course printed, and theoretically it would be about the same as if we adopted it to-night, excepting this—that it would not have the official endorsement. We would then have the advantage of placing it before the public, and if any suggestions or amendments were made, of profiting by them in the final adoption of the report of the Committee, which date might be fixed at any time in the course of two or three months. It might be fixed for the May meeting when there will probably be more present from out of town than there are now I see no reason why one or two months would not be ample time in order to elicit all the criticisms there might be upon it.

THE PRESIDENT:—The Chairman understands the motion to be that we receive and adopt the report and that it be printed. Is this the understanding of the mover?

MR. J. S. BROWN:—My understanding is that we were to accept this report and place it on the minutes and leave it then to the consideration of the members. At least that is my desire personally. In other words that we accept it, but do not adopt it as going forth as the work of the Institute as a whole. I think the suggestion of the Secretary to leave its final adoption by the Institute until the May meeting would be wisest and best. I would, therefore, move that the report be accepted and printed in our Transactions with that understanding.

MR. MAILLOUX:—If this gentleman decides to change the wording of his original motion, I think that my amendment is in order. My amendment was that it be adopted.

THE PRESIDENT:—The resolution will have to stand as it was offered unless the Institute make no objection to the change. If

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there is any objection to changing the resolution of course it would have to be put as it was offered. Amendments are in order. Of course we must receive the report before we can adopt it, and the Chair has therefore understood that the motion was to receive and adopt the report. Now if there is any objection to changing that so as to put it that we simply receive the report, the chair will have to put the motion as first understood—that we receive and adopt the report.

MR. R. W. POPE:—I move an amendment, that it be received without the word adopt. Is that in order?

THE PRESIDENT:—That is in order.

MR. POPE:—That it be received and printed in the Transactions.

(The amendment was seconded.)

THE PRESIDENT:—The amendment is that the word adopt be omitted from the motion. Those in favor of the amendment will please make it manifest by saying Aye; opposed No.

(The amendment was carried.)

MR. MAILLOUX:—I move the report be adopted.

THE PRESIDENT:—The motion before the house is that the report be received. We have just voted that the word adopt be omitted from the motion. Now the original motion comes before the house that the report be received and printed for distribution. Are there any further remarks on the motion? If not, the chair will put the motion. All those in favor of receiving and printing the report will please make it manifest by saying Aye; contrary minds No.

(The motion was carried.)

MR. MAILLOUX:—I move that the report be adopted.

(The motion was seconded.)

THE PRESIDENT:—It is moved and seconded now that the report be adopted. Are there any remarks upon this motion?

MR. BIRDSALL:—I understand the motion to mean that the report be adopted to-night.

THE PRES DENT:—That is the motion as I understand it.

MR. BIRDSALL:—I would like to offer an amendment that the report be brought up for adoption two months from to-night.

THE PRESIDENT:—The chair would hardly consider such a motion as that in order. The motion now is that the report be adopted.

MR. THORBURN REID:—I move we lay this motion on the table until the second meeting following this.

THE PRESIDENT:—It is moved and seconded that the motion lie on the table for two months. The question of time can be discussed. All those in favor of the motion that it lie on the table for two months please make it manifest by saying Aye; contrary minds No.

(The motion was carried.)

MR. R. W. POPE:—There is another committee, on the unit of self-induction.

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MR. CROCKER:—The Committee on the value of the unit of self-induction, the Henry, has held one or two meetings, but is hardly yet able to report. We find that the ordinary practical values of self-induction vary from about 1/100 to 10 quadrants, therefore, the average value is a little less than one quadrant. This means that in order to express self-induction in quadrants within one per cent. you have got to go to the second or third decimal place. Therefore, in order to express all common values in whole numbers, which is desirable, it will be necessary to fix the Henry at about one-thousandth of the quadrant. Then we should very seldom have to use decimal fractions in expressing the value of self-induction. I merely state these points in order that the Institute may be informed as to the progress of our work and the general facts of the case. I think the matter better lay business over until the next meeting when we expect to be able to report.

THE PRESIDENT:—The next business will be the reading of a paper by Dr. Louis Bell upon "The Theory of Compound Winding for Constant Potential."

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*A paper read at the 51st Meeting of the American Institute of Electrical Engineers, New York, November 18th, 1890, President W. A. Anthony in the chair.*

# ON THE THEORY OF COMPOUND WINDING FOR CONSTANT POTENTIAL.

BY DR. LOUIS BELL.

I wish to preface this paper by stating that there is in it nothing revolutionary, nor any radically novel attempt to discuss a problem that has already been treated by more skilful hands than mine. It is simply an effort to bring the theory of compound winding to a practical basis, indulging in no complicated formulæ and introducing no constants that can not be conveniently determined in practice. To this end I shall consider the subject synthetically rather than analytically, starting from the plain shunt winding and considering those terms which must be introduced to take account of the failure of shunt winding to give constant potential. I do not think that compound winding should be considered as anything more than a method of improving a shunt machine already well designed; it certainly never should be called upon to avoid the evil effects of bad design.

For the systematic treatment of the subject I would introduce the following notation, which differs slightly from that most often employed, but is convenient for the purpose in hand.

Let $C_x$ represent the current on the line;

$C_s$, the current in the shunt coils;

$R$, the resistance of shunt coils;

$r$, the resistance of armature and series coils combined;

$E$, the E. M. F. of the machine running light;

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$e$, the fall of potential due to armature resistance;
$N$, the number of convolutions in shunt coils;
$n$, the number of convolutions in series coils;
$m$, the number of convolutions on armature;
$a$, $b$, $c$, the three terms of $n$;
$l$, the angle of lead;
$q$, the magnetic resistance of machine on open circuit;
$q_x$, the magnetic resistance of machine at full load, and
$p$, the value of $q_x$ divided by $q$.

I shall consider especially the long shunt arrangement, though, as will be seen later, the short shunt leads to practically the same results.

The first and obvious cause of fall of potential at the terminals of the machine is due to the fact that the armature has a resistance; as the current increases, a certain amount of potential is absorbed in the armature, and consequently the available E. M. F. at the terminals falls. The amount of decrease is evidently proportional to the resistance in the armature and the current through it.

$$e = r\ C_x$$

To compensate this loss we must furnish an increase of induction sufficient to produce $e$ additional E. M. F. If the field magnets and the armature core were quite unsaturated, that is, if we could neglect to change in permeability, we should simply increase the total ampere-turns to an amount sufficient to compensate the fall in potential. Let $a$ be the series turns capable of producing this at full load, neglecting change in permeability, then

$$a = \frac{N r}{R}$$

But the permeability decreases as we put on this additional induction. The magnetic resistance $q$ at the start will have increased to a certain other value $q_x$. We must therefore increase the number of series turns to take account of this added resistance, and we have

$$a = \frac{N r}{R} p$$

It will be observed that this quantity does not have to be multiplied by the coefficient of leakage because we have simply reduced the shunt turns to equivalent series turns, and conse-

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quently have already included it. This formula will be at once recognized as practically equivalent to that given by Thompson in his well-known book, and at this point Thompson drops the investigation, merely mentioning incidentally some of the other causes which necessitate compounding. Thompson's formula:

$$\frac{Z}{S}=\frac{r_s}{r_s+r_m}\times\frac{q_1}{q_0}$$

is not quite the same as mine for the reason that while his $q_0$ is proportional to the permeability when there is no external current, his $q_1$ is proportional not to the permeability at maximum current, but to the mean permeability between no load and full load. Hence if $Z$ is taken as the number of shunt turns required to give the desired potential on open circuit, Thompson's formula will inevitably give too few series turns for the reason just mentioned, if for no other. But since by adding series turns the magnetic resistance is increased, the shunt winding which produces $E$ volts on open circuit will not do so at full load. Additional series turns must then be employed to compensate for this and since the change in shunt ampere turns must be from $NC$ to $NCp$, the number of series turns to be added to compensate for the decreased effect of the shunt will be

$$b=\frac{\frac{NE}{R}(p-1)}{C_x}$$

This term also includes the coefficient of leakage for the same reason as before.

It will be noticed that both $a$ and $b$ include the quantity $p$, and here is met the principal difficulty in effecting the compounding. It is my purpose to show that this quantity $p$ can be obtained from known data with sufficient accuracy for the purpose in hand. It will evidently be a quantity little in excess of unity and in practical machines may range from 1.05 to 1.50, although in certain cases it may even exceed the latter figure. Thompson gives the case of a certain Siemens compound machine in which $p$ would be over three. This, however, must have had a very insufficient amount of iron in the magnets or the armature core, or both. We fortunately do not have to deal with dynamos of such bad design very frequently. Provided we have known enough about the iron to be used in a given machine to design the shunt winding intelligently, we shall also

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know enough to design the compound winding. If we have at hand the characteristic curve of a similar shunt machine, $p$ can be determined very easily from it. I give herewith the data for the Manchester machine described by Dr. Hopkinson. I have simply taken the apparent permeability from his characteristic curve.

| When magnetizing force equals | | | 1,000 | induction / magnetizing force equals | | 470 |
|---|---|---|---|---|---|---|
| " | " | " | 2,000 | " | " | 465 |
| " | " | " | 3,000 | " | " | 460 |
| " | " | " | 4,000 | " | " | 460 |
| " | " | " | 5,000 | " | " | 460 |
| " | " | " | 6,000 | " | " | 451 |
| " | " | " | 7,000 | " | " | 443 |
| " | " | " | 8,000 | " | " | 425 |
| " | " | " | 9,000 | " | " | 400 |
| " | " | " | 10,000 | " | " | 377 |
| " | " | " | 11,000 | " | " | 353 |
| " | " | " | 12,000 | " | " | 333 |

If the permeability curve of the iron is known even approximately we can obtain $p$ from it quite readily. In Plate 1, let $a\ b$ be the permeability curve. The permeability at no load corresponds to the point $d$, that at full load to the point $f$. Now lay off the ordinate $d\ e$ so that the ratio between $d\ e$ and $c\ d$ equals the ratio between the iron resistance and the air resistance of the proposed machine, then lay off from the point $f$ the ordinate $f\ g$ equal to $d\ e$, and draw $g\ h$. Then the ratio of the lengths $h\ c$ and $e\ c$ corresponds to the quantity $p$ required. Plate 2, drawn from Hopkinson's figures, gives numerically the change in permeability for cast-iron. The figures relating to the Manchester machine were, of course, for wrought-iron cores and cast-iron poles. It is thus evident that a rather close approximation to the value of $p$ can be made if we know anything about the iron that we are going to use. Now as we shall see later, and as is indeed evident at the start, $a$ and $b$ are of about the same order of magnitude. I do not think that $b$ will ever be negligible in a practical machine unless $a$ is also negligible, and there is, therefore, little need for compounding. When the magnets are anywhere near saturation $b$ will be much larger than $a$, but both $a$ and $b$ combined will not give the proper number of series turns for constant potential unless the armature is run with no load, and therefore produces no demagnetizing effect. The approximate demagnetizing effect of the armature has been investigated by Hopkinson and is as follows:

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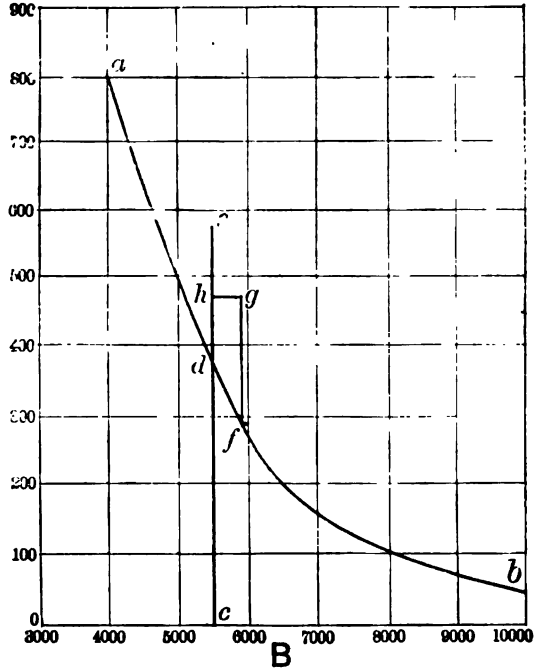
$$4\pi C\frac{m}{2}\frac{2l}{\pi} = 4\,l\,m\,C.$$

In other words, it is due to the convolutions included in twice the angle of lead. For constant potential we must add then $c$ turns in series equal

$$\nu m \frac{l}{\pi}$$

It is evident at once that a change in lead will affect the com-




B
Plate I.

pounding; an increased lead will cause the machine to under-compound, a decreased lead to over-compound. As, however, the amount of distortion in the field depends largely on the shape of the extremities of the pole-pieces, the above uncertain factor in compounding can often be gotten rid of by a little care in designing the poles.

It is obvious that the term $c$ is to include the coefficient of leakage. Uniting now, the three terms, $a, b$ and c, we have finally, as the completed formula for compound winding, the following:

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$$n = p\left(\frac{Nr}{R} + \frac{\frac{NE}{R}(p-1)}{C_x} + \nu m \frac{l}{\pi}\right)$$

It now may be interesting to see how well this formula applies to practical machines. I regret to say that I have been unable to get full details of any machine which gave exact compounding, but I have obtained an assortment sufficiently large to show in a general way the application of the formula.

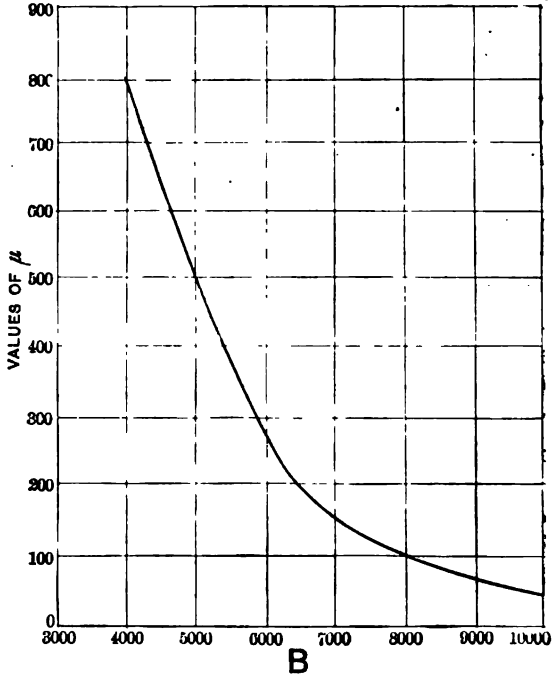


Plate 2.

Machine No. 1, 110 volts, 8 amperes, over-compounded 2 volts. For this small machine take $p$ equal to 1.2. Applying the formula, $a$ equals 14, $b$ equals 44, $c$ equals 15; total series turns by formula, 73; actual number, 90.

Machine No. 2, 110 volts, 3 amperes, over-compounded 3 to 5 volts; $a$ equals 2, $b$ equals 7, $c$ equals 7; total series turns by formula, 16; actual number, 28.

Machine No. 3, 500 volts, 20 amperes; $p$ equal to 1.1, $a$ equals 3, $b$ equals 15, $c$ equals 14; total turns by formula, 33, actual number, 60. Machine over-compounded 3 to 5 volts.

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Machine No. 4, 110 volts, 200 amperes, over-compounded 5 volts; $p$ equals 1.05; lead rather large; $a$ equals 2, $b$ equals 2, $c$ equals 5; total turns required, 9; actual number, 12.

Machine No. 5, 500 volts, 60 amperes; $p$ equals 1.05, over-compounded about 7 per cent. $a$ equals 3, $b$ equals 5, $c$ equals 4; total 12; actual number, 32,

Machine No. 6, 500 volts, 90 amperes; $p$ equals 1.05; $a$ equals 3, $b$ equals 4, $c$ equals 4; total turns should be 11; actual number, 19. Machine over-compounded like the former.

Machine No. 7, 500 volts, 150 amperes, $p$ equals 1.05; over-compounded 7 per cent. $a$ equals 3, $b$ equals 3, $c$ equals 3; total, 9; actual number of turns, 28.

Machine No. 8, 100 volts, 30 amperes, $p$ equals 1.1, $a$ equals 13, $b$ equals 46, $c$ equals 25; total, 84; actual turns, 56. Machine over-compounded about 2 volts, and the shunt winding did not bring the potential up to the 100 volts intended.

These are merely rough figures, obtained without the use of even the permeability curve of the iron—simply by estimation from permeability curves at hand. It will be seen, however, that all the over-compounded machines got from the formula too few series turns, while the under-compounded machine gave too many. I think that the discrepancy is of about the right order of magnitude, although we cannot verify it accurately without the curve of the iron.

It remains to consider some few further points regarding compounding. If the winding is designed to give the same potential at practically no load and at full load, it necessarily follows that at some point between, the potential will rise; for, while the magnetizing force changes along a line, the magnetic resistance changes along the corresponding curve between the same points.

An approximate idea of the amount of irregularity in potential may be gained from Fig. 1. Connect in this diagram $d$ and $f$ by a straight line. From its middle point drop an ordinate upon the axis. The length intercepted between the straight line and the permeability curve then gives the error in compounding, by comparison with the total change of magnetic resistance.

It should be noted that the formula I have given determines the compound winding for a given assumed potential produced by a shunt coil alone; therefore, if the machine is to be run at a slightly different speed from that at first intended to produce this given voltage, the compounding is still correct, for it per-

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tains to the voltage, rather than to the speed. If the speed of a correctly compounded machine be raised and the current in the shunt kept constant, it will tend to over-compound. If the current in the shunt is allowed to increase, the change in resistance will decrease the relative power of the series coils, and the machine will under-compound.

It now only remains to glance at some of the formulæ heretofore given. That of Thompson I have already incidentally discussed. That of Frölich (perhaps the best we have had) should receive mention here. Frölich takes account of the change in permeability by introducing a quantity $f$. Like Thompson, his formulæ involve two points of saturation. It should be said here that there is no special black magic about the half saturation point of a dynamo, any more than about the three-sevenths or the seven-thirteenths saturation point. In very many cases it happens to be about the point at which the machine is used. Kapp, in his well-known and excellent book, takes account of the change in permeability with a fair degree of approximation, by the use of his tangent function.

All these attempts at the proper theory of compounding depend, like the one which I have just presented, on forming some sort of an estimate on the change in magnetic resistance of a dynamo, due to adding a certain amount of induction. Without some approximate method of finding this quantity, the problem is indeterminate, and the special thing which I have endeavored to show is that from the data already at hand about iron, we can form a sufficiently close estimate of the value of the coefficient $p$, without either knowing the characteristic of the machine, or indulging in endless approximations. I hope that some practical designer will look into the values that $p$ takes in his machines, and I believe that it can be readily enough obtained to permit of quite accurate compounding, by the use of the formula I have given. The introduction of the terms $b$ and $c$ I regard as important. Their existence has been well known, but I do not think they have received the attention that I have endeavored to to show they deserve.

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[Note Communicated by Dr. Bell since the Discussion.]

I am much indebted to Mr. J. B. Entz for calling attention, in the course of the discussion to an apparent increase in the mag-

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netic resistance of the air gap as the load is increased. I say apparent increase, because it is hard to separate increase of magnetic resistance from counter magnetomotive force supposed by some to be caused even while the armature is running without load. In applying a formula similar to my own, and, like it, including change in permeability and armature reaction as well as armature resistance, Mr. Entz found that his formula gave only about 80 per cent. of the series turns actually required. This was in the case of Edison machines, and while not knowing the exact character of his formula I am unable to compare it fully with my own, I am inclined to agree with him that the observed discrepancy is probably due to increase of the resistance of the air space rather than to counter magnetomotive force. It has been before this pointed out, that while a dynamo is running, the lines of force do not pass radially across the air space, but are skewed by the magnetism of the armature so that the actual path must be somewhat greater than the apparent one. I am surprised, however, that the difference should reach the amount observed. It certainly would not do so in machines like the Wenstrom, having a very small air space. The total effect on the magnetic resistance of the machine would be of course proportional to the ratio between the magnetic resistance of the iron and of the air gaps, and would increase when the relative value of the latter increased. The amount of increase of air resistance due to increased load probably varies quite systematically with the ratio of armature ampere turns to field ampere turns, but the exact amount of this variation, disturbed as it is by the effect of the polar extremities, is a subject for further investigation. If the lines of force were skewed 45 or even 30 degrees from a radial direction over any considerable portion of the air gap there would certainly be a very perceptible effect on the magnetic resistance of the dynamo. In any case, however, if the amount of skewing can be even roughly estimated this added magnetic resistance can very readily be taken account of in the formula I have proposed. To do this it would only be necessary to take account of the change in laying out the line $f\ g$ in Plate 1. On drawing $g\ h$ we should then have a value of $p$, including the change in resistance due to the cause mentioned. I shall take up this question in detail, for a sufficiently simple and convenient method of estimation can probably be found that will enable the correction to be introduced into my formula by the above very easy method so as to give a result sufficiently exact for all practical purposes.—L. B.

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## Discussion.

Mr. Townsend Wolcott :—In the paper by Mr. Esson, which was published in the *Electrical World*, there is a formula given for compounding machines, or rather a variation of the ordinary formula for calculating the field turns. Mr. Esson adds to the formula of Hopkinson another term consisting of thiry-three per cent. of the ampere turns on the armature. There is one other term however in a compound machine. This thirty-three per cent. of the ampere turns does not take into consideration the loss of potential due to resistance of the armature. Mr. Esson says that in his Phœnix dynamo he adds 165/1000 of the number of armature turns to each field coil. That is to compensate for the resistance in the armature, and backward induction has rather more effect in reducing the potential of the terminals than the armature resistance has, and he stated that in the Victoria dynamo it is about twice as great. In connection with that backward induction I would like to make another remark. According to the figures of Mr. Esson and some others, the backward induction from a Gramme armature is greater than from a Siemens, which is contrary to what we would expect. By ampere turns on the armature he means one half the product of the convolutions by the current. Now in a Gramme armature, each turn surrounds only half the iron in the armature, while in the Siemens it surrounds the whole iron. But as a practical fact Mr. Esson thinks that thirty-three per cent. for the Gramme armature is about right. I would like Dr. Bell's opinion on that subject, as I see he does not use a term of that kind.

Dr. Bell :—When it comes to the question of armature resistance and the relative effect of armature resistance and the armature turns, it depends entirely upon the type of machine, as I showed by the figures there. The attempts that have generally been made to compound have consisted in a sort of guessing at what was about the right proportion and finding it experimentally for one type of machine. Once found, it holds fairly well for that type. Now my term $c$ takes care of the armature turns and the term $a$ takes care of its resistance. I think the reason why Mr. Esson found the Gramme armature gave more distortion to the field was due to the fact that the Gramme armature admits of forming definite poles, so to speak more readily. It is not in this case cross-magnetizing a cylinder of iron of considerably greater length than diameter, but it is magnetizing the ring so as to get one pole at each brush, which I think gives a rather more definite pole at that point and makes more trouble in the field. Now its effect for the same number of ampere turns in producing backward induction may be the same. As a matter of fact I think the Gramme armature produces a greater disturbance of the field and therefore must run with more lead. Therefore the term $b$ would be larger.

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MR. WOLCOTT:—It would seem to me that the two things were nearly synonymous—the backward induction and the distortion of the field. In consequence of the tendency of the armature to form poles cross-wise, there results a distortion of the field. That is what we call the backward or cross-induction, as I understand it, and as the intensity of induction is always less in the Siemens armature, it would seem that the variations of the amperes would naturally cause greater variations in that part of the magnetism of the armature which is due to the current in the armature wire. The Gramme armature has usually double the induction of the Siemens, unless the latter is made with the centre cut out.

DR. BELL:—The backward induction and the distortion are two totally different things. The presence of the distortion is the unfortunate cause of the backward induction. Of course they are really due to the same ampere turns; but if there is anything that causes a violent local distortion of the field it will raise such trouble about sparking that we shall have to set the brushes over, and in doing that, shall have the plane of magnetization of the armature so that it produces a severe backward induction. If we so arrange the pole-pieces that there will not be any sparking to speak of, you can run any kind of an armature you please and run it in either direction and it will not spark, and you can set the brushes without lead. If you arrange the pole-pieces so that you can get a certain amount of distortion without causing sparking you need not trouble yourself very much about the backward induction.

MR. A. E. KENNELLY:—I wish to point out one thing, namely that it is good practice to over-compound dynamos—for this reason: that you seldom, if ever, have your delivery at the machine terminals. If your attention be confined to the point of delivery, say a mile away from the dynamo, it may be interesting to know that under all loads that dynamo is delivering a constant potential difference at its terminals, but if you have to maintain a constant potential difference at your feet, the fact that the potential difference is constant at the machine terminals does not altogether help you. Therefore if you over-compound your machine so as to take care of the fall of potential in your conducting wire, which is in a certain sense a resistance of the armature according to the extended view that the author of the paper to-night gives, by including a series winding with the armature, you then have the means of maintaining the potential difference constant at your point of delivery. If the resistance of the leads to your supply is not definite or constant, then you cannot so compound the machine as to give a constant delivery of potential difference, because one of the factors is a variable. For that reason the only source of adjustment left you is a shunt, for example, upon the series winding. That is an arrangement which is comparatively familiar. And while the paper gives us very clearly and ex-

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plicity three of the prominent factors that are necessary to take into account for the compounding of machines, I think that the fourth factor deserves some attention. Also the third term $c$ is really only an approximation—$c$ is more complicated than that looks unfortunately; although, perhaps the complication is not of very great practical importance.

Dr. Bell:—Mr. Kennelly is quite right in saying that it is desirable to over-compound a machine, and of course by including the resistance of the line in that small $r$ you have got the compounding for a distant point as has been pointed out by Thompson. We need some slight further change in the formula, however, because you still further increase the saturation, and therefore the value of $p$ would rise slightly; but if you know about how much you want to over-compound the machine, you can apply the formula just as readily to over-compound for a given rise of potential as for straight compounding. It simply requires using a different value of your induction. The armature term is unfortunately more complicated; but the term $c$ is a fair approximation to it in ordinary cases. The cross-induction in the armature, particularly where the amount is considerable, assumes a very disagreeably complex form, but that is perhaps as ready an approximation as the present state of the art admits, and I have omitted together with the further complications of the armature, a considerable number of small periodic terms, etc., which are of the second order compared with those three more prominent ones.

Mr. Crocker:—I agree with Mr. Kennelly that the formula for practical purposes, ought to consider the line of resistance just exactly as much as the armature resistance, and there always is some line resistance with every armature resistance in practical cases. A maker should either have his machines compounded with reference to the use they are to be applied to or adopt an approximate over-compounding which would apply to most cases. We know that most isolated plants ought not to have over five per cent. drop between the dynamo and lamps and they rarely have less than three per cent. drop; therefore four per cent. over-compounding would probably be within one per cent. of right in most practical cases. I would also like to say, in regard to the third term $c$ of Dr. Bell's formula that it may have considerable value without any distortion at all. The brushes can stand practically at right angles to the line joining the centres of the pole-pieces and yet that "back-induction" as it is called will still have a very considerable effect in reducing the E. M. F. I have some ideas on that subject and I am now proving them experimentally. As to "back-induction" I think that is a very unfortunate name. I consider "back-magnetization" better. The word induction is over burdened, I think. It is used in "static-induction," "self-induction" and "mutual induction" as well as in its ordinary sense.

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MR. JUSTUS B. ENTZ:—I have used that formula and compared it with the averages of about three thousand machines of the Edison Company. These averages were revised about every six months and after a while there might be a difference of about one quarter per cent. between them; and in no case did that formula give more than 80 per cent. of the additional ampere turns necessary for compounding. I got an exact measurement of the angular movement brushes on the machine. I knew the point on the curve of the dynamo as we call it. That is to say the percentage of increased magneto motive force necessary for one per cent. increase of lines of force. Say the ratio of the increase of ampere turns to the increase of magnetism, and most of them were at such a point on their characteristic curve that it requires about two per cent. additional ampere turns of the field to raise the voltage of the machine 1%. If we had five per cent. drop in the machine at the point 2 to 1 on the curve, it would need for that ten per cent. more armature turns. The term $c$ is taken nearly the same way it is there, and is added to the armature term $a$. But there is an additional leakage from the pole-pieces due to the back ampere turn in the armature which is also calculated from knowing the point on the curve. But in no case did the sum of these terms come over 80 per cent.

DR. BELL:—May I ask how you got the value of $p$?

MR. ENTZ:—I say I took the term $a$ and $b$ as one. I found by actual test on the machine just what per centage of ampere turns was necessary for a given increase in voltage or for a given increase in induction.

DR. BELL:—I do not quite understand whether you got that term $p$ at all. If you did not take the term $p$ corresponding to the real magnetic resistance, of course you would not get a correct result.

MR. ENTZ:—It was taken. You have got a simple ratio of magnetic resistance between no load and full load. Say the resistance of the total circuit has increased at the rate of two per cent. for one per cent. increase of induction in the machine, that would correspond to a point of 3 to 1 on the curve, and the ampere turns would have to be increased two per cent. for the increased resistance of the magnetic circuit plus one per cent. for the increased lines.

DR. BELL:—That makes it a linear increase, which it certainly is not.

MR. ENTZ:—Of course it varies. It is a curve like any saturation curve, and is different for different voltages of the same machine. For instance if the iron is at such a point that for one per cent. increase of induction its resistance increases two per cent., then in calculating the additional ampere turns necessary, they would be directly proportional to the drop in volts for the air magnetic circuit, and they would be; not directly proportional for the iron circuit but proportional, to the increased induction times the increased resistance of the iron.

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DR. BELL:—I think I see the difficulty now. If you compound the air resistance and the iron resistance, you will get the apparent permeability of the machine, as you seem to have done in that case. You could have any given value as saturation, a certain definite value of the ampere turns, but that is not at all getting to the point $p$ in the formula.

MR. ENTZ:—I know. You have got a quantity there for $p$ of about 1.1. If the drop in that machine were five per cent. it would mean that the magnetic resistance of that machine had increased ten per cent. what I would call three; 1 on the curve. It comes to exactly the same thing.

DR. BELL:—But how do you account for the extra ampere turns required?

MR. ENTZ—I do not think the lines of force stand in the same plane.

DR. BELL:—In other words you think there is a specific increase of resistance due to the induction of the armature?

MR. ENTZ:—No; due to the tension of the lines.

DR. BELL:—Due rather to the cross-induction of the armature—skewing the line so to speak.

MR. ENTZ:—Yes, due to the line being dragged around after the armature, and I found a constant to express those terms which is proportional to the current intensity of the armature over the magnetic intensity of the field.

DR. BELL:—Have you tried that formula on any exactly compounded machine?

MR. ENTZ—On an exactly compounded machine.

A MEMBER:—How does Dr. Bell calculate the angle of lead? In a case I had the other day, in a 10,000 watt machine $a$ and $c$ were exactly equal.

DR. BELL:—You can get the angle of lead in any type of machine that you know anything about, quite approximately. For instance in a machine that I had to consider it varied from $\frac{1}{20}$ to $\frac{1}{10}\pi$. Now if the cross-induction is really a large quantity with no lead at all, that would fully account for all the discrepancies we have just considered. Then you could not determine any armature turns that would account for it at all. But that does represent it approximately, I think, though it would be too small rather than too large.

MR. ENTZ:—If the brush was kept on the neutral line according to that formula the volts would only drop due to the drop of the armature. That is if the field was independently excited.

DR. BELL:—Plus possible distortion that you mentioned.

MR. ENTZ:—I say that is so according to that formula, but it is not so, because I have tested machines in that way.

DR. BELL:—That is probably due to the increase of resistance in the air space.

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MR. ENTZ:—That is what I think. I do not think the lines stand in the same place as at no lead.

MR. MAILLOUX:—With regard to the role played by the armature current. I hold views similar to those just advanced by Mr. Entz; and in endeavoring to analyze the reactions occuring there, I have for some years past been accustomed to consider the change of magnetic resistance under different conditions as being due to the change of path of the magnetic lines of force. The phenomenon is indeed one which has been long since well recognized. If I am not mistaken it has been commented upon in scientific papers, notably by Mr. Snell, in England. At any rate it is so familiar to me that I would scarcely be able to tell where I first learned of it—where the impression first arose. I think if we stop to analyze the reaction which will take place in the presence of current in the armature, we will very quickly see that the presence of current and the reaction attending it must change the distribution of the lines of force. That change of distribution is followed by a rapid re-distribution at each commutation of a section. We must consider it as taking place at a very great velocity and being distributed or broken up again at a very great velocity, but not necessarily at the same velocity. Now there can be no doubt, and I think the facts substantiate it, that when there is current passing through the armature it distorts the lines of force. It is as if the armature wires moved them bodily a short distance, the space of one section, more or less, at each commutation and thus lengthened their lineal path, so that the portion of the total or gross magnetic resistance which is due to the air-gap will be materially lengthened, because the lines of force are stretched out by the current, carried onward, and they will not cut the armature wires until they have been carried forward further the greater the armature current. I think that is really where we get the difference of magnetic resistance between no load and large load, although a certain variation takes place in the magnetic circuit itself in consequence of hysteresis There is no doubt a slight disturbance there which is the analogue of the spurious resistance due to self-induction in electrical circuits. We have an inductive, magnetic resistance, so to speak, a "live" magnetic resistance, truly inductive in one sense.

I have noticed further that this armature resistance increment is a certain function of the lead. That is another fact which nearly all who have had practical experience with dynamos must have noticed. I would like to know from the author of the paper or any other person present if there is any information as to what kind of a function it is of the angle of lead. I think it is a matter of the greatest interest, theoretically and practically.

DR. BELL:—I think Mr. Mailloux is right in saying that the increment of resistance is a function of the angle of lead, but I am afraid it is also a function of the shape of the pole-pieces and two or three other things of a somewhat difficult character to bring

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into any simple treatment. If the increment so to speak of air resistance, plus perhaps an increased change of induction, because both may enter as well as one, rises as Mr. Entz's remarks would seem to indicate, to a perceptible amount at least in smooth armatures, I should think that a fair approximation might be made by the process, which is apparently tried practically of adding an estimated amount to the air resistance. In other words this would amount to adding a certain amount to the air resistance. I attempted to get this quantity $p$ by taking the permeability curve of the iron and laying off an ordinate from the point of no load, a quantity proportional to the air resistance. Now taking the equal line $f\,g$ and drawing $g\,h$, I obtain this quantity $p$. If that added air resistance amounts to a considerable quantity I should say that it might be very readily taken care of in any type of machine about which we know anything, by simply taking a distance here on $f\,g$, say to a point $g$, in other words, being mindful of the fact that the air resistance increases as well as the iron resistance. If we can form any approximate idea as to the amount of this increase we can take account of it in this very simple may, which would give the value of $p$, that would give the correct number of turns for compounding. If the air resistance varies in any lineal way or any reasonably simple sort of curved way, that graphical method would give a value of $p$ to take into account the increase in air resistance. I would like to have Mr. Entz try that.

MR. ENTZ:—I say we found it very nearly proportional to the current density of the armature divided by the magnetic density.

DR. BELL:—In other words it varies lineally.

MR. ENTZ:—Yes.

DR. BELL:—In that case it may be very easily taken into account by simply bearing in mind the lineal change in laying off the second line $f\,g$. That would give us the value of $p$ including the total change in resistance, which would then give the correct number including that, and this would be a comparatively simple term added to our theory of compounding. Being a lineal quantity it is very readily handled and will admit, I think, of getting the correct value of $p$ by this graphical method which will bring the commutation out right.

THE PRESIDENT:—Are there any further remarks on the paper of Dr. Bell? If not we will call for the second paper on the programme, by Mr. Steinmetz.

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*A paper read at the 51st meeting of the American Institute of Electrical Engineers, November 18th, 1890.*

# A NEW METHOD OF ANALYZING ARMATURE REACTIONS OF ALTERNATORS.

BY CHAS. STEINMETZ.

It results from the discussion of Mr. Reid's paper, read before the Institute last month that the assumption of the constancy of $N$, the field magnetism and $\rho$, the magnetic resistance of an alternator, can not generally be considered true enough to be accepted, and therefore the equations given by Mr. Reid can not be considered complete, although being very valuable on account of their simplicity.

To complete those equations by taking into consideration the pulsating nature of the field magnetism, which fluctuates by more than 50% in the kind of alternator tested, as shown in the paper of Messrs. Tobey and Walbridge, and by considering the periodical variations of $\rho$, we start from the fundamental equation (6), given in Mr. Reid's paper.

By substituting equation (8), this equation (6), takes the form:

$$E = -\frac{d}{dt}\left\{ S N \cos \frac{2\pi}{T} t + S^2 \mu i \right\}, \qquad (1)$$

where we introduce, instead of the magnetic resistance $\rho$, its inverse value, the magnetic conductivity,

$$\mu = \frac{1}{\rho}, \qquad (2)$$

in order to make the equation hold also for the other method of considering the phenomena, by means of the term "coefficient of self-induction," this being proportional to the magnetic conductivity by the equation:

$$L = S^2 \mu. \qquad (3)$$

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Substituting: $E - Ri$, introducing the transformation:

$$= \frac{2\pi}{T} t, \tag{4}$$

and substituting,

$$s = \frac{T}{2\pi}, \tag{5}$$

we get:

$$s R i = -\frac{d}{d\varphi}\left\{ S N \cos\varphi + S^2 \mu i \right\}; \tag{6}$$

or, expanded:

$$S^2 \mu \frac{di}{d\varphi} + s R i + S^2 i \frac{d\mu}{d\varphi} = S N \sin\varphi - S\cos\varphi \frac{dN}{d\varphi}, \tag{7}$$

as the complete differential equation of the phenomenon.

Now we have to consider $N$, $\rho$ and $\mu$ also as periodic functions of the time $t$, and therefore of the angle $\varphi$; but as such functions, which have two periods during one period of the alternating current, and therefore, as univalent periodics, they must have the form:

$$\begin{aligned} N &= F + \varkappa_1 \sin 2\varphi + \varkappa_2 \sin 4\varphi + \ldots. \\ &\quad + \beta_1 \cos 2\varphi + \beta_2 \cos 4\varphi + \ldots. \\ \mu &= \sigma + \zeta_1 \sin 2\varphi + \zeta_2 \sin 4\varphi + \ldots. \\ &\quad + \xi_1 \cos 2\varphi + \xi_2 \cos 4\varphi + \ldots. \end{aligned}$$

In the first approximation, by using only the first three terms of each expression, and making some changes, these equations assume the form:

$$\left.\begin{aligned} N &= F - G\cos(2\varphi - \alpha) \\ \mu &= \sigma - \gamma\cos(2\varphi - \vartheta) \end{aligned}\right\} \tag{8}$$

Substituting these values in equation (7), we get:

$$S^2\left\{\sigma - \gamma\cos(2\varphi - \vartheta)\right\}\frac{di}{d\varphi} + s R i + 2 S^2 \gamma i \sin(2\varphi - \vartheta) =$$

$$= SF - SG\left\{\sin\varphi\cos(2\varphi - \alpha) + 2\cos\varphi\sin(2\varphi - \alpha)\right\}, \tag{9}$$

the complete differential equation of an alternator, where $\alpha$ is the angle of lag of the field magnetism, and $\vartheta$ the angle of magnetic lag, caused by hysteresis and eddy-currents.

This equation (9) is integrated by the periodic function:

$$i = A\sin\varphi + B\cos\varphi + C\sin 3\varphi + D\cos 3\varphi, \tag{10}$$

if we neglect the exponential factor of the integral, which gives the phenomena in starting the alternator, but disappears after a few thousandths of a second.

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Value (10) substituted in equation (9) gives us, after cancelling all the terms of tertiary order: $G\gamma$, $C\gamma$, $D\gamma$, etc., and making a few changes, for the determination of the coefficients $A$, $B$, $C$, $D$, an identical equation in $\sin\varphi$, $\cos\varphi$, $\sin 3\varphi$, $\cos 3\varphi$.

The coefficients of this equation placed 0, give us four equations, from which we get:

$$A = \frac{S}{\varepsilon^2 R^2 + \sigma^2 S^4}\left\{\varepsilon R F + \frac{G}{2}(\sigma S^2 \sin\alpha - \varepsilon R\cos\alpha) - \frac{\gamma F S^2}{2}\sin\vartheta\right\}$$

$$B = -\frac{S}{\varepsilon^2 R^2 + \sigma^2 S^4}\left\{\gamma F S^2 - \frac{G}{2}(\sigma S^2\cos\alpha + \varepsilon R\sin\alpha) + \frac{\gamma F S^2}{2}\cos\vartheta\right\} \quad (11)$$

$$C = \frac{3S}{2(\varepsilon^2 R^2 + 9\sigma^2 S^4)}\left\{\frac{\gamma F S^2}{\sqrt{\varepsilon^2 R^2 + \sigma^2 S^4}}[\varepsilon R\sin(\vartheta - \varepsilon) + 3\sigma S\cos(\vartheta - \varepsilon)] - \sigma G[\varepsilon R\cos\alpha - 3\sigma S\sin\alpha]\right\}$$

$$D = \frac{3S}{2(\varepsilon^2 R^2 + 9\sigma^2 S^4)}\left\{\frac{\gamma F S^2}{\sqrt{\varepsilon^2 R^2 + \sigma^2 S^4}}[\varepsilon R\cos(\vartheta - \varepsilon) - 3\sigma S\sin(\vartheta - \varepsilon)] + \sigma G[\varepsilon R\sin\alpha + 3\sigma S\cos\alpha]\right\}.$$

These values substituted in equation (10), give, after cancelling again the terms of tertiary order, substituting (5), and calling the number of periods per second,

$$n = \frac{1}{T}, \quad (12)$$

the expression for the armature current in the alternator:

$$i = \frac{2\pi n F S}{R\sqrt{1 + \frac{4\pi^2 n^2 \sigma^2 S^4}{R^2}}}\sin(\varphi - \varepsilon) - \frac{\pi n G S}{R}\left\{\frac{\sin(\varphi - \alpha - \varepsilon)}{\sqrt{1 + \frac{4\pi^2 n^2 \sigma^2 S^4}{R^2}}} + \frac{3\sin(3\varphi - \alpha - \eta)}{\sqrt{1 + \frac{36\pi^2 n^2 \sigma^2 S^4}{R^2}}}\right\} - \frac{2\pi^2 n^2 \gamma F S^3}{R^2\sqrt{1 + \frac{4\pi^2 n^2 \sigma^2 S^4}{R^2}}}\left\{\frac{\cos(\varphi - \vartheta)}{\sqrt{1 + \frac{4\pi^2 n^2 \sigma^2 S^4}{R^2}}} - \frac{3\cos(3\varphi - \vartheta - \varepsilon - )\eta}{\sqrt{1 + \frac{36\pi^2 n^2 \sigma^2 S^4}{R^2}}}\right\} \quad (13)$$

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where we introduced the substitutions:

$$\frac{2\pi n \sigma S^2}{R} = \tan \varepsilon \,, \tag{14}$$

$$\frac{6\pi n \sigma S^2}{R} = \tan \eta = 3 \tan \varepsilon, \tag{15}$$

the angle of lag of the armature current.

From this equation (13) we get the square root of the mean square, or the effective current:

$$I = \frac{\sqrt{2}\pi n F S}{R\sqrt{1+\frac{4\pi^2 n^2 \sigma^2 S^4}{R^2}}}\left\{1 - \frac{G}{2F}\cos a - \frac{\pi n \gamma S^2 \sin(\vartheta - \varepsilon)}{2R\sqrt{1+\frac{4\pi^2 n^2 \sigma^2 S^4}{R^2}}}\right\}. \tag{16}$$

The first term of this expression is the value given in Mr. Reid's paper under equations (15), (17), (19), and therefrom the E. M. F.:

$$E = \frac{\sqrt{2}\pi n F S}{\sqrt{1+\frac{4\pi^2 n^2 \sigma^2 S^4}{R^2}}}\left\{1 - \frac{G}{2F}\cos a - \frac{\pi n \gamma S^2 \sin(\vartheta - \varepsilon)}{2R\sqrt{1+\frac{4\pi^2 n^2 \sigma^2 S^4}{R^2}}}\right\}. \tag{17}$$

For a CONSTANT POTENTIAL alternator, where the self-induction of the armature current is low enough to be neglected, equation (17) assumes the form:

$$E = \sqrt{2}\pi n F S\left\{1 - \frac{G}{2F}\cos a - \frac{\pi n \gamma S^2 \sin(\vartheta - \varepsilon)}{2R}\right\} \tag{18}$$

Here again the first term is given in Mr. Reid's paper under figure (20).

For a CONSTANT CURRENT alternator, where the self-induction of the armature is so high that the other terms may be neglected, equation (16) takes the form:

$$I = \frac{F}{\sqrt{2}\sigma S}\left\{1 - \frac{G}{2F}\cos a - \frac{\gamma}{4\sigma}\sin(\vartheta - \varepsilon)\right\} \tag{19}$$

its first term given in Mr. Reid's paper in equation (16.)

If there are no precautions taken against the fluctuations of

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the field current, angle $\alpha$ approximates 0; and cos $\alpha$ therefore $= 1$.

On the other hand, the influence of the second term, the fluctuations of the exciting current, can be decreased by increasing angle $\alpha$, therefore decreasing cos $\alpha$; that is, by throwing self-induction in the exciting circuit.

This latter phenomenon I had occasion to observe some time ago, the potential of an alternator, which I tested, being raised from 22 volts to 160 volts by means of two impedance coils (transformers with open secondary), connected in the exciting circuit.

An approximate calculation shows that, although the term of magnetic saturation, the third term, in equations (16) to (19), is small enough to be neglected in most cases, the second term, which accounts for the influence of the fluctuations of the exciting current, can not well be neglected.

Even the equations given above can hardly be considered as an absolutely complete solution of the problem of armature reactions of alternators, because they still neglect terms of tertiary order.

But they will be found to hold for almost all the types of modern alternators, and only in those few machines, where the fluctuations of the field current are unusually heavy, (especially where the electric induction is produced by changes of the magnetic resistance, and field magnetism and armature magnetism are connected in series in the magnetic circuit), do those fluctuations become so important, that a more particular calculation of them, including the consideration of the self-induction in the field circuit, has to be made. Into this, however, I do not need to enter deeper, because such machines, although they were operated many years ago (Klimenko's alternator, for instance, tested at the Electrical Exhibition in Vienna, 1883), have not come into more extensive commercial use.

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## Discussion.

Mr. Thorburn Reid :—Mr. Chairman: It has given me great pleasure to find that Mr. Steinmetz has been able to make use of my equations to carry the analysis on to a further degree of approximation. I have not attempted to apply them to any machine except that of Mr. Stanley's, described at our last meeting, and as I found them amply sufficient for that purpose, I did not go any further. Having accomplished the purpose with which I started the analysis, I laid it aside to go into other matters requiring more immediate attention. Mr. Steinmetz's approximation would, I have no doubt, be of use in some forms of alternators with which I have not come in contact and I see that he mentions one case where they would have been immediately applicable. Now in regard to the application of the method to the Stanley arc machine, I saw the difficulties he mentioned before I finished the analysis. But as I mentioned at the last meeting, considered them of small enough value to be neglected. The large variation of the field current shown by Messrs. Tobey and Walbridge's paper rather staggered me at first, but on thinking over the matter I came to the conclusion that that fluctuation is not as great as it appears at first sight. Mr. Steinmetz remarks that the *magnetism* varies more than 50 per cent., but if he will consider the matter he will see that not the magnetism but the *field current* varies 50 per cent. Now those of you who are familiar with Ewing's curves of hysteresis will remember that he forms some loops in those curves by stopping the current at some point and going back on its tracks a little way, returning to his starting point, and if you remember the form and position of those loops you will see that they show the magnetism as varying very little with an enormous variation in the E. M. F. and especially is this the case where the saturation is high as it is in Mr. Stanley's alternator. Thus a very small variation in the magnetism will account for a very large variation in the current. Therefore the constant $a$ equation (8) is likely to be very much smaller than would appear at first sight. Further, a reference to the curves in Messrs. Tobey and Walbridge's paper shows that the lag of the field current varies only a few degrees from short circuit to full load and that its maximum almost exactly coincides with that of the armature current. Therefore the value of the magnetic flux at the instant when the armature pole is opposite the field pole must vary very little since the instantaneous values at the maximum point are varying very slowly. Taking all these points into consideration then it appears to me that the influence of this term will be vanishingly small and even if it were not so, there are so many other variations at least as large affecting the result that the addition to this term would be of doubtful utility for practical purposes and even for theoretical, unless other variations are also allowed for.

The third term in Mr. Steinmetz's equation (19), he appar-

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ently does not consider of importance nor do I. Not, however, because it is small, though it may be as far as I know, but because its effects would be impossible of prediction in view of the other variables of which no account has been taken as yet, and which I will now mention.

From Mr. Steinmetz's second equation, I judge he must have been mistaken in the meaning that I gave to $\rho$ in my paper or else overlooked the importance of some terms that are left out of that equation, supposing them to be constant. $\rho$ is not equal to the reciprocal of $\mu$ but to $\mu$ multiplied by $L$ divided by $A$. Both $L$ and $A$ are variable during the revolution of the armature and their variation is probably much greater than that of $\mu$. Of course the variation will have to be added to that of the magnetic circuit; and right here another complication will step in, namely the fact that, as resistance is added in the main circuit more lines will go through the iron inside the coil and less through the iron around the coil. The resistance of these two parts of the magnetic circuit will thus be changed to a considerable extent. In other words, $\mu$ will change not only during a revolution of the armature, but also while the resistance is being changed in the main circuit. One more complication that has not been considered and I will stop, though I might mention others. The fluctuation of the field current is affected by the various varying values of $\mu$, by the change in the magnetic resistance due to rotation of the armature and the eddy currents which must be considerable, since the field is not laminated. There is every reason to believe then that in Mr. Stanley's machine at least, the terms introduced in Mr. Steinmetz's equation will not materially help us, in view of the number of other terms, equally as important which would have to be introduced to completely solve the problem. As I have said before, the equation I obtained, agrees nearly enough with the actual performance of the machine for all practical purposes and furnishes a means of designing the machine intelligently. In applying these equations, I had to do it by means of the curve of current and electro-motive force obtained in practice. There was no way that I could get up, of measuring the length and cross-section of the magnetic circuit of the armature. I obtained the value of $\rho$ by means of one point on the curve of current and E. M. F. which is obtained by practice, and substituted in the equation. Now that is a very rough method, but what I discovered was that my equation agreed with the curve, or rather the curve was very nearly expressed by my equation, so that it appears to me that the equation was close enough for all practical purposes.

I hope neither Mr. Steinmetz nor any one present will think that I am underrating the importance of the equation which he has evolved in so masterly a manner. He has had experience with machines which I have never been called on to analyze, and the terms that I have neglected may be of great importance in

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those machines and the other difficulties may be so small as to not materially affect the result. In that case his equation will, no doubt, be of great value and in any case it is important as throwing more light on a very difficult and complicated analysis and some one who has more time and a better knowledge of mathematical processes than I have, may be Mr. Steinmetz himself, may be able to take in the other variations and obtain a complete analysis of the machine. I would like to suggest to Mr. Steinmetz the question as to whether it would not throw more light on the matter to carry out his sine series to a further point in view of the many variables that affect the final result. This I am afraid, however, would lead to so complicated an equation that it would be impossible to determine the constants, not to speak of the integration. Some of the higher orders may be of more importance also than those included.

MR. STEINMETZ:—I can hardly remember all the remarks Mr. Reid offered here, and can answer therefore only a few, which I just remember.

In regard to the term $\mu$ in equation (2), I believe Mr. Reid misunderstood me. I introduced this $\mu$ only for convenience's sake, as the inverse value of the term $\rho$, which Mr. Reid used; but this $\mu$ has nothing do do with the "magnetic susceptibility" or "specific magnetic" conductivity, as follows from the equation (3).

The eddy-currents induced in the field iron of the machine, and the hysteretic lag are accounted for already in my equations by the angle of lag of field magnetism $a$, and its amplitude $G$.

Furthermore, these constants $F$, $G$, $a$, $\lambda$, $\vartheta$, can very well and easily be calculated, although I did not go further into the consideration of these terms, because I intended to give only a short note on this analytical method.

If I proposed to determine these constants, I would try the following way:

The terms $F$, $G$, $a$ are very much independent of the armature circuit, and depend especially upon two factors:

1. The shape of the iron circuit of the machine.

2. The self-induction of the field circuit, and, if this is not laminated, but an ordinary cast-iron field, the amount of eddies induced therein.

Only a certain part of the lines of magnetic force, induced by the armature current, will go through the magnetic field circuit, and this part will be greater or smaller, according to the shape of the magnetic field circuit; for instance pretty small for a smooth armature or an armature with wide overlapping teeth, still smaller for a disc armature and long, highly saturated field magnets, larger in those fly-wheel types of alternators very often proposed and hardly ever used.

Let $\delta$ = this percentage of armature lines going through the field circuit.

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In the alternator which I referred to at the last meeting, this percentage was 1, that is, all the armature lines went through the field circuit; the machine was intentionally built so, for carrying out some experimental researches. This feature explains the unusually heavy fluctuations of the field current in this particular machine.

Then the whole number of armature lines going through the field circuit will be:

$$M^1 = \delta S \mu i \cos \varphi$$

and the number of lines produced by the field exciting current proper therefore:

$$N - M^1 = F - G \cos (2 \varphi - \alpha) - \delta S \mu i \cos \varphi$$

where for the current only the first term of equation (13) is sufficiently exact:

$$i = \frac{2 \pi n F S}{R \sqrt{1 + \frac{4 \pi^2 n^2 \sigma^2 S^4}{R^2}}} \sin (\varphi - \varepsilon)$$

Now $c$ being the field exciting current, $S^1$ the number of field turns, $\mu^1$ the magnetic conductivity of the field circuit, the number of lines induced by the field current is:

$$= S^1 \mu^1 c$$

and, this being $= N - M^1$

gives us the differential equation for the determination of $F$, $G$, $\alpha$ which differential equation still contains the term $c$, the field current:

This field current is obtained in the following manner:

May $E$ denote the E. M. F. of the exciter dynamo, $r$ the field resistance. The E. M. F. induced in the field circuit by the fluctuations of the magnetism is then:

$$e = - S^1 \frac{d N}{d t} = - \frac{2 S^1 G}{s} \sin (2 \varphi - \alpha)$$

and the field current is:

$$c = \frac{E - \frac{2 S G}{s} \cos \omega \sin (2 \varphi - \alpha - \omega^1)}{r}$$

where $\omega$ and $\omega^1$ give the shifting of phase and the decrease of amplitude, caused by self-induction and by the eddy-currents in the field iron, calculated by the well-known equations of inductive resistances and transformers (the eddy-currents taking the place of the secondary current in the transformer, for no eddies $w = w^1$).

This value $c$ substituted in the equation derived before:

$$N - M^1 = S^1 \mu^1 c$$

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gives us a simple differential equation in $2\varphi$, which can be integrated very easily, and gives the proper values $F$, $G$, $a$.

In regard to the periodic function $\mu$, the amplitude $\lambda$ is the decrease of magnetic conductivity for the maximum saturation used in the alternator, and to find the shifting of phase $\theta$, we may assume that the minimum of $\mu$ occurs together with the maximum of current $i$, with a small advance of phase $\psi$ due to hysteresis, (so that the minimum of $\mu$ takes place a little before the current $i$ reached its maximum.)

Then we have $2\varphi - \theta = O$ for: $\varphi - \varepsilon = 90° - \omega$ and therefore: $\theta = 180° + 2\varepsilon - 2\psi$

or: $\theta = 2\varepsilon - 2\psi - 180°$

DR. PUPIN:—I would like to make a very short remark only. Mr Steinmetz obtained the wave of the current to be composed of several waves. Some having the period of the alternator and others having a triple period; besides, the waves differ in phase. That would mean that the resultant wave would have a larger lag than found experimentally, and it would also mean that the wave which they obtained experimentally would not be a simple harmonic wave, but would have kinks in it. It follows from the fundamental differential equation for the currents in an alternator that as soon as we have two periodic quantities in it besides the current—that the solution cannot give us a periodic function which is a simple harmonic. We have seen that as soon as an arc-lamp is introduced into the circuit, there is introduced besides the variable coefficient of mutual induction $N$, another simple harmonic variable which is the resistance of the total circuit, and we obtain, as was shown experimentally, a complex harmonic for the wave. In the case, however, where we have incandescent lamps in the circuit a simple harmonic wave is obtained for the current and E. M. F. It follows therefore that every integral which gives us anything but the simple harmonic for an incandescent circuit disagrees with the experimental facts.

I find that if we introduce $N$ as a simple harmonic function, but let $\rho$ remain constant we really obtained a simple harmonic wave, which is in perfect agreement with the experimental facts, and a short consideration shows that $\rho$ is really a constant. $\rho$ depends on two things; first, on the permeability of the iron in the armature, and secondly on the permeability of the iron in the field magnets. Now if the saturation of the iron in the armature is not carried beyond nine or ten thousand lines of force to the square centimetre, then the coefficient of permeability remains practically constant, as we know from Ewing's curves. Now I was told by Mr. Reid at the last meeting that the magnetization of the iron in the armature was not carried beyond nine or ten thousand lines of force per square centimetre. Therefore, as far as the armature is concerned, the quantity $\rho$ in Mr. Reid's paper

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or $\mu$ in Mr. Steinmetz's paper is a constant quantity. Next we have to examine what influence has the iron in the field magnets upon the coefficient of permeability of the armature circuit? The iron in the field magnets is magnetized to a pretty high degree of saturation; perhaps fourteen thousand, perhaps twenty thousand lines of force to the square centimetre. The armature current acts always in such a way as to tend to demagnetize the iron in the field magnet. Now we know when iron is highly magnetized, if a force be applied in the opposite direction tending to demagnetize it, that the resistance of the iron to the second force is almost as great as the resistance of air. I heard this fact first mentioned by Mr. Eickemeyer of Yonkers, a man who has large practical experience in these matters, and I examined that point also from Ewing's curves. It really follows, when iron is magnetized to a considerable degree of saturation, that if we apply a force in the opposite direction to demagnetize it, that for forces smaller than the force which produced the first magnetization, the coefficient of permeability is almost as small as that for pure air. Therefore as far as the magneto-motive force of the armature current is concerned, the magnetic resistance of the field magnet is the same as that of air. Therefore the magnetic resistance opposed to the magneto motive force of the armature current depends only on the condition of the iron in the armature and therefore as long as that iron is not magnetized above the ten thousand lines of force to the square centimetre, the magnetic resistance opposed to the current in the armature is constant throughout, and if we make that supposition in our differential equation and substitute for $N$ the induction due to the field magnet, a simple harmonic function as I suggested at the last meeting, (the conditions of our problem suggest a simple harmonic function for it) if we make that substitution for $N$, we get a solution exactly the same as Mr. Reid's, only the constants will differ somewhat; the wave of the current will be a simple harmonic wave, and that is just what the experiment found it to be.

MR. STEINMETZ:—I made the same observation, that by assuming only $N$ as variable, the differential equation of the alternator gives a finite integral.

But, having spoken of the variability of the term $\rho$ in the last meeting, I thought it my duty to get the variability of $\mu$ into the equations too, to make them complete, although a numerical calculation showed me that at least in the alternator tested by Messrs. Tobey and Walbridge this third term is rather small and unimportant, as I already stated in my paper, so that it does not show up in the current curves

I just now remember another remark in Mr. Reid's answer, about the decrease of the fluctuations of field magnetism due to hysteresis. It is not hysteresis alone, which causes a discrepancy between field magnetism and field exciting current, but those

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considerations given above for calculation of the field constants $F$, $G$, $a$, etc., show that the field magnetism does not go together with the exciting current, but differs in phase, and has a smaller amplitude than the current, because of the eddy currents and of the "back-induction" to use this improper term, from the armature circuit to the field.

Adjourned.

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# American Institute of Electrical Engineers.

Associate Members Elected at Council Meeting, September 16th, 1890.

| Name. | Address. | Endorsed by |
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| BRADDELL, ALFRED E. | Electrical Inspector, Underwriters' Association, Middle Dep't, 308 Walnut St., Philadelphia, Pa. | T. C. Martin. Joseph Wetzler. R. W. Pope. |
| KNIGHT, WM. B. | Civil Engineer (Specialty Cable and Electric Railways), 200 West 6th St., Kansas City, Mo. | M. E. Bates. Geo. W. Mansfield. Wm. H. Wiley. |
| KEEN, WILLIAM B. | Electrician, The Clark Electric Co., 478 Pearl St., New York City. | E. P. Clark. Edw'd P. Thomson. R. W. Pope. |
| TABER, ROBERT B. | Secretary and Electrical Engineer, New Bedford Gas Light Co., New Bedford, Mass. | Wm. Brophy. C. J. R. Humphreys. Wm. Lee Church. |
| MCCAY, H. K. | Electrician, Edison Electric Light Co., Box 439, Birmingham, Ala. | W. S. Andrews. C. J. Field. Leigh Carroll. |
| NESMITH, S. D. | Ohio Agent, United Edison Mfg. Co., 322 Society for Savings Building, Cleveland, Ohio. | H. Ward Leonard. Wm. H. Peirce. E. M. Izard. |
| HEWITT, CHARLES | Engineering Dep't, The Sprague, Electric Railway and Motor Co., 273 Hicks St., Brooklyn, N. Y. | F. J. Sprague. Joseph Wetzler. Chas. Cuttriss. |
| RODMAN, SAMUEL, JR. | Lieut. 1st Artillery, U. S. A., Fort Columbus, N. Y. Harbor. | S. W. Roessler. E. L. Zalinski. O. T. Crosby. |
| FORBES, FRANCIS | Lawyer, 137 Broadway, New York City. | Joseph Wetzler. Chas. Cuttriss. T. C. Martin. |
| TOBEY, WILLIAM BOARDMAN | Dep't Electrical Engineering, Cornell University, Student, Class of 1890. | Harris J. Ryan. Edw'd L. Nichols. Franklin L. Pope. |
| LOOMIS, OSBORN P. | Electrician, Eureka Electric Co., 530 Nostrand Ave., Brooklyn, N. Y. | Joseph Wetzler. T. C. Martin. E. R. Knowles. |
| WOOLF, ALFRED E. | Electrician and Inventor, Woolf Electrical Co., 864 Lexington Ave., New York City. | Townsend Wolcott. Joseph Wetzler. R. W. Pope. |

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| ATWOOD, GEO. F. | Edison Laboratory, Orange, N. J. | A. E. Kennelly. C. J. Reed. F. Schulze-Berge |
| BINNEY, HAROLD | Assistant in the Practice of Patent Law, with Gilbert M. Plympton, 245 Broadway, New York City. | H. C. Townsend. T. C. Martin. Edw'd P. Thompson. |
| PUTNAM, H. ST. CLAIR | Treasurer and Electrician, Thomson-Houston Carbon Co., Fremont, O. | H. A. Foster. E. W. Rice, Jr. A. L. Rohrer. |
| PERRINE, FREDERIC A. C. | Superintendent Insulated Wire Dep't. John A. Roebling's Sons Co., 137 E. State St., Trenton, N. J. | Joseph Wetzler. T. C. Martin. R. W. Pope. |
| MERRITT, ERNEST | Instructor in Physics, Cornell University, Ithaca, N. Y. | E L. Nichols. H. J. Ryan. W. A. Anthony. |
| HALL, WILLIAM P. | President. The Hall Signal Co., 50 Broadway, New York City. | Geo. W. Blodgett. F. L. Pope. R. W. Pope. |

Total 18.

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Council Meeting, October 21st, 1890.

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| Name. | Address. | Endorsed by |
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| ABBOTT, ARTHUR V. | Mechanical Engineer. United Electric Traction Co., Closter, N. J. | Joseph Wetzler. T. C. Martin. Geo. M Phelps. |
| BULKLEY, J. NORMAN | Superintendent, U. S. Aluminum Metal Co. Boonton, N. J. | Alex. S. Brown. Chas. R. Cross. R. W. Pope. |
| COLLEY, BENJAMIN W. | First Asst. Superintendent, The Commercial Cable Co., Hazel Hill, N. S. | S. S. Dickenson. Jos. Wetzler. Geo. M. Phelps. |
| FESSENDEN, REGINALD A. | Assistant Electrician, U. S. Electric Light Co., Newark, N. J. | Thos. A. Edison. A. E. Kennelly. Louis Bell. |
| FITCH, GRAHAM D. | First Lieut. Corps of Engineers, U. S. A. Duluth, Minn. | Gilbert Wilkes. Cary T. Hutchinson. W. S. Andrews. |
| GAINES, J. D. | Second Assistant Superintendent, The Commercial Cable Co. Hazel Hill, N. S. | S. S. Dickenson. Jos. Wetzler. Geo. M. Phelps. |
| LLOYD, ROBERT McA. | Electrician of the Marion, N. J. Factory, United Electric Traction Co, 2 W. 36th St., N. Y. C. | Jos. Wetzler. Geo. M. Phelps. J. C. Chamberlain. |
| MARTIN, F. | Inspector of Isolated Plants, Edison Electric Illuminating Co., of N. Y., 16 Oak St., Newark, N. J. | Jos. Wetzler. T. C. Martin. R. W. Pope. |
| MARTIN, J. | Electrician, Hanson, Van Winkle & Co., 16 Oak St., Newark, N. J. | Jos. Wetzler. T. C. Martin. R. W. Pope. |
| MILLER, WM. C. | Gen. Man., Watervliet Turnpike & R. R. Co., 3 South Hawk Street, Albany, N. Y. | J. C. Chamberlain. Geo. M. Phelps. T. C. Martin. |
| PERKINS, FRANK C. | Student in Electrical Engineering, Cornell University, Ithaca, N. Y. | Edwd. L. Nichols. Ernest Merritt. Harris J. Ryan. |

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| REID, THORBURN | Consulting Electrical Engineer, and Expert, 15 Wall and 26 E. 33d Sts., New York City. | Wm. Stanley, Jr.<br>Henry Morton.<br>Wm. E. Geyer. |
| ROSENBERG, E. M. | Supt. Manhattan E. L. Co., 80th St. and Ave. B. Residence, 784 Lexington Ave., N. Y. City. | H. A. Foster.<br>W. E. Geyer.<br>J. A. Seely. |
| SCHMID, ALBERT | Superintendent, Westinghouse Electric & Mfg. Co., Pittsburgh, Pa. | O. B. Shallenberger.<br>Nikola Tesla.<br>Jos. Wetzler. |
| SHEBLE, FRANKLIN | Electrical Engineer, Thomson-Houston Electric Co., Lynn, Mass. | Jas. B. Cahoon.<br>E. W. Rice, Jr.<br>A. L. Rohrer. |
| WATSON, ROBERT | The Elektron M'f'g Co., 79 Washington St., Brooklyn, N. Y. | T. C. Martin.<br>Jos. Wetzler.<br>Geo. M. Phelps. |
| WEBB, HERBERT LAWS | Assistant Electrician, The Metropolitan Telephone and Telegraph Co., 18 Cortlandt, and 159 W. 94th St., N. Y. City | Geo. A. Hamilton.<br>T. C. Martin.<br>Geo. B. Prescott, Jr. |
| WELLER, HARRY W. | Railroad Inspector, The Edison General Electric Co., Edison Building, Broad Street, New York City, and Jamaica, N. Y. | J. H. Vail.<br>D. C. Jackson.<br>Jos. Wetzler. |
| WRIGHT, JOHN D. | Electrician's Assistant, United Electric Traction Co., 107 Garrison Ave., Jersey City, N. J. | Jos. Wetzler.<br>Geo. M. Phelps.<br>R. W. Pope. |

Total 19.

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Council Meeting, November 18th, 1890.

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| Name. | Address. | Endorsed by |
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| DICKERMAN, GEORGE W. | Ass't to General Manager, Eureka Electric Co., 173 Fifth Ave.. New York City. | Osborn P. Loomis.<br>Gilbert Wilkes.<br>R. W. Pope. |
| DONNER, WILLIAM H. | Designing Draughtsman, and Electrical Engineer, Thomson-Houston Electric Co., 113 Franklin St. Lynn, Mass. | C. J. Van Depoele.<br>A. L. Rohrer.<br>Edward Weston. |
| LOGAN, CHARLES H. | General Manager, Standard Electric Co., Detroit, Mich. | W. J. Hammer.<br>Geo. M. Phelps.<br>Joseph Wetzler. |
| OTTEN, DR. JAN D. | Engineer, Thomson-Houston International Electric Co., Michaelsbrucke 1, Hamburg, Germany. | A. L. Rohrer.<br>E. W. Rice, Jr.<br>Louis J. Magee. |

Total 4.

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Council Meeting, December 16th, 1890.

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| Name. | Address. | Endorsed by |
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| ALEXANDER, P. H. | President, Alexander, Barney and Chapin, 20 Cortlandt St., New York City. | R. W. Pope.<br>T. C. Martin.<br>Jos. Wetzler. |
| DRESSLER, CHARLES E. | Maker of Scientific and Electrical Apparatus, College of the City of New York, 17 Lexington Ave. New York City. | Alfred G. Compton.<br>Chas. A. Doremus.<br>H. A. Foster. |

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| FRENCH, E. L. | Draughtsman, Mather Electric Co., Manchester, Conn. | W. A. Anthony. D. C. Jackson. David E. Lain. |
| HANDLEY, ARTHUR | Electrical Engineer, Electrical Engineering Co. of Ireland, L't'd, 61 Dawson St., Dublin, Ireland. | R. W. Pope. T. C. Martin. Jos. Wetzler. |
| MAYER, GEORGE | Mechanical Draughtsman, Edison General Electric Co., 68 Broad St., New York City. | A. E. Kennelly. A. E. Winchester. J. H. Vail. |
| MURPHY, WM. F. | Electrician, Spartanburg Electric Light and Power Co., Spartanburg, S. C. | R. W. Pope. Jos. Wetzler. T. C. Martin. |
| PAINE, F. B. H. | Consulting Electrical Engineer, Chas. Paine & Sons, 71 Broadway, New York City. | Charles A. Terry. H. M. Byllesby. Albert Schmid. |
| POOR, CHAS. LANE | Tutor, College of the City of New York, 17 Lexington Ave., New York City. | Alfred G. Compton. Chas. A. Doremus. Francis B. Crocker. |
| SHELDON, SAMUEL, *A. M. Ph. D.*, | Professor of Physics and Electrical Engineering, Polytechnic Institute, Brooklyn, N. Y., Residence, 20 Sidney Pl. | Geo. M. Phelps. James Hamblet. T. C. Martin. |
| SPRUSON, WILFRED J. | Member of the firm of Hepburn & Spruson, Consulting Engineers and Electricians, 169 King St., Sydney, Australia. | W. J. Johnston. Louis Bell. Clarence E. Stump. |
| SULLIVAN, M. C. | With the *Electrical Engineer*, 150 Broadway, New York City. | Jos. Wetzler. T. C. Martin. R. W. Pope. |
| WARING, JOHN | Consulting Electrician, The Perkins Electric Lamp Co., Manchester, Conn. | W. A. Anthony. D. C. Jackson. David E. Lain. |

Total 12.

## TRANSFERS FROM ASSOCIATE TO FULL MEMBERSHIP.

Approved by Board of Examiners, December 3, 1890, Confirmed by Council December 16, 1890.

| | | Elected Associate Member |
|---|---|---|
| BINNEY, HAROLD | Assistant in the Practice of Patent Law, 245 Broadway, N. Y. | Sept. 16th, 1890. |
| DONNER, WILLIAM HERBERT | Designing Draughtsman and Electrical Engineer, T-H Electric Co., Lynn, Mass. | Nov. 18, 1890. |
| FESSENDEN, REGINALD A. | Assistant Electrician, U. S. Electric Light Co , Newark, N. J. | Oct. 21, 1890. |
| HUTCHINSON, DR. CARY T. | Electrical Engineer, 56 West 25th St., N. Y. | Feb. 7th, 1890 |
| PERRINE, DR. FREDERIC A. C. | Supt. Insulated Wire Dept., Roebling's Co., Trenton, N. J. | Sept. 16th, 1890 |
| WEBB, HERBERT LAWS | Asst. Electrician, Metropolitan Telephone and Telegraph Co., New York. | Oct. 21st, 1890 |
| WOLCOTT, TOWNSEND | Consulting Electrician, 849 Greene Ave., Brooklyn, N. Y. | Mar. 6th, 1888. |

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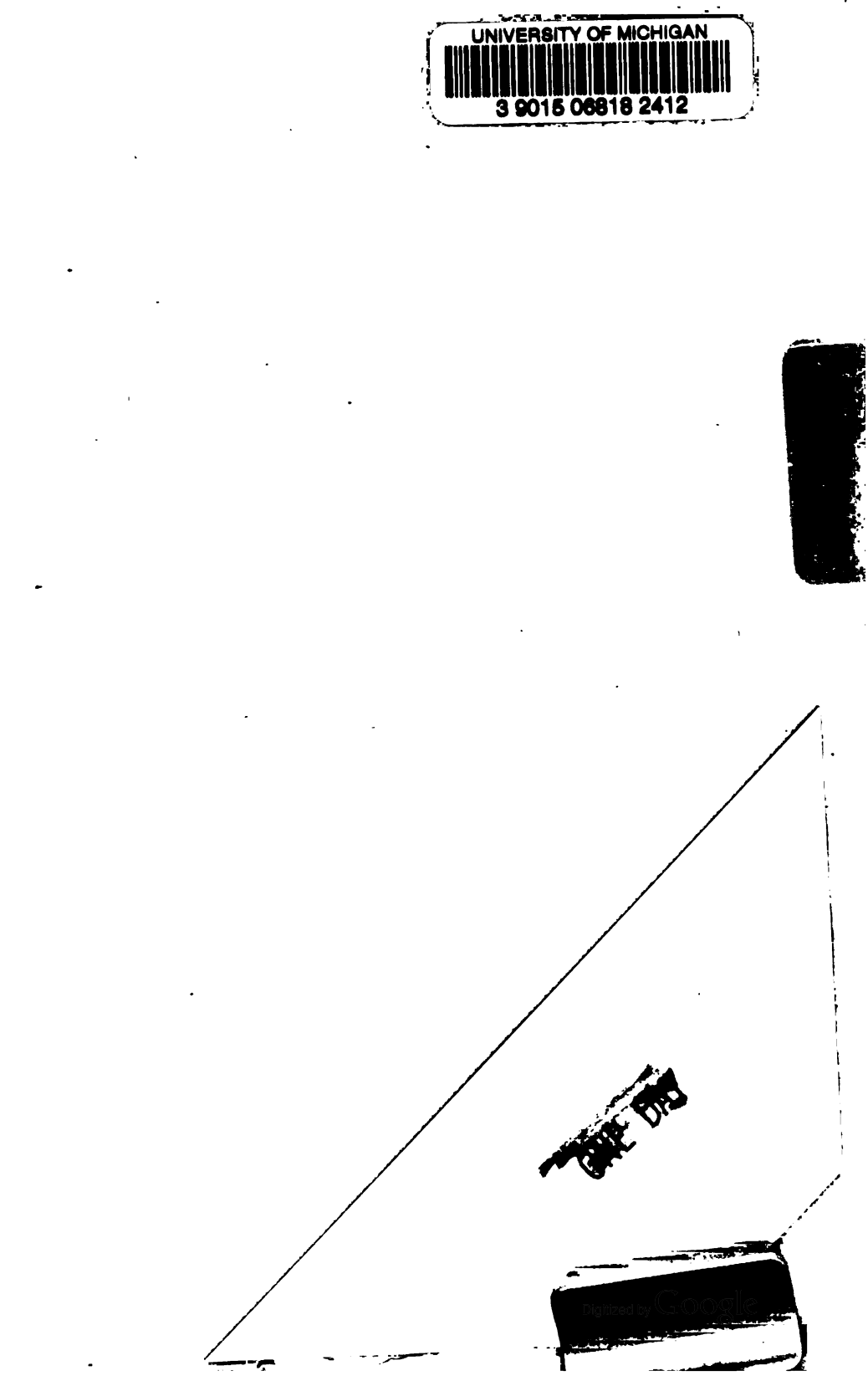


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